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Modeling of the Electrical Environment

New England Clean Energy Connect Transmission Project

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CENTRAL MAINE POWER COMPANY, Request for Approval of a Certificate of Public Convenience and Necessity for the New England Clean Energy Connect Consisting of the Construction of a 1,200 MW HVDC Transmission Line from the Québec-Maine Border to Lewiston (NECEC) and Related Network Upgrades; Docket No. 2017-00232

Modeling of the Electrical Environment

New England Clean Energy Connect Transmission Project

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Acronyms and Abbreviations

A	Amps
AC	Alternating current
BPA	Bonneville Power Administration
CMP	Central Maine Power Company
DC	Direct current
EPRI	Electric Power Research Institute
FDA	Food and Drug Administration
G	Gauss
Hz	Hertz
ICES	International Committee on Electromagnetic Safety
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ions/cm^3	ions per cubic centimeter
kV	Kilovolt
kV/m	Kilovolts per meter
mG	Milligauss
MW	Megawatt
NECEC	New England Clean Energy Connect
NRPB	National Radiological Protection Board
ROW	Right of way
V/m	Volts per meter

Limitations

At the request of Central Maine Power Company (CMP), Exponent, Inc. (Exponent) calculated the electric- and magnetic-field levels and ion densities for transmission lines associated with the proposed New England Clean Energy Connect Transmission Project. This report summarizes work performed to date and presents the findings resulting from that work. In the analysis, we have relied on information provided to us by CMP and its consultants with respect to components and configurations of the transmission lines. CMP has confirmed to Exponent that the data contained herein are not subject to Critical Energy Infrastructure Information restrictions.

The findings presented herein are made to a reasonable degree of engineering and scientific certainty. Exponent reserves the right to supplement this report and to expand or modify opinions based on review of additional material as it becomes available, through any additional work, or review of additional work performed by others.

The scope of services performed during this analysis may not adequately address the needs of other users of this report, and any re-use of this report or its findings, conclusions, or recommendations presented here are at the sole risk of the user. The opinions and comments formulated during this assessment are based on observations and information available at the time of the investigation. No guarantee or warranty as to future life or performance of any reviewed condition is expressed or implied.

Executive Summary

Central Maine Power Company has proposed the New England Clean Energy Connect (NECEC) project to deliver electricity to Maine over an approximately 145.3-mile ±320-kilovolt (kV) direct current (DC) transmission line (Section 3006) from the Québec-Maine border at Beattie Township to the proposed Merrill Road Converter Station in Lewiston. A 345-kV alternating current (AC) line (Section 3007) approximately 1.6 miles long will connect Merrill Road Converter Station to the existing Larrabee Road Substation. To accommodate the additional power coming into Maine, a new 26.5 mile 345-kV AC line (Section 3027) will be constructed between Coopers Mills Substation and Maine Yankee Substation. Finally, two existing 115-kV AC lines (Sections 64 and 62) will be rebuilt in the 16-mile corridor between Larrabee Road Substation and Surowiec Substation.[1] Over the majority of the route, the NECEC project is planned to be constructed on existing transmission corridors. For modeling purposes, the route is divided into three configuration types based upon the proposed construction of the line:

1. **DC-Only–**This configuration will contain proposed Section 3006, an overhead ±320-kV DC transmission line on a new right of way (ROW).
2. **DC+AC–**This configuration will contain the proposed Section 3006 (overhead ±320-kV DC) adjacent to existing 115-kV transmission lines.
3. **AC-Only**–The AC only configuration will contain:
   a. Proposed Section 3007, a 345-kV interconnection from Merrill Road Converter Station to Larrabee Substation.
   b. Proposed Section 3027, a 345-kV transmission line adjacent to existing 34.5/115/345-kV transmission lines.
   c. Rebuilt Sections 64 and 62, 115-kV transmission lines and other short segments.[2]

[1] Section 62 will be rebuilt in only 9.3 miles of this 16-mile corridor between Crowleys Substation and the Surowiec Substation.

[2] Full descriptions of the project components are included in Volume 2 of the NECEC Petition for a Certificate of Public Convenience and Necessity at Section C.

The route is divided in this way because the electrical environment and hence the calculation methodology varies among these three configurations. Beneath an overhead DC transmission line, the electrical environment includes static electric fields, static magnetic fields, and space charge (i.e., mostly air ions and some charged aerosols). Beneath an overhead AC transmission line, the electrical environment includes 60-Hertz (Hz) AC electric and magnetic fields. Where both AC and DC lines will be present, as in the combined-DC+AC ROW, the static and AC electric and magnetic fields were calculated and presented independently (as well as space charge for the DC line) due to the differences between static and AC fields.

Static Electric and Magnetic Fields

The DC line will produce static electric and magnetic fields similar to those encountered in the natural environment, with magnetic-field levels similar to the Earth's static geomagnetic field and electric-field levels similar to those produced by atmospheric phenomena, weather, and friction charging.

The calculated static electric-field levels everywhere on the route are below the National Radiation Protection Board's recognition that static fields above 25 kV/m may be annoying (NRPB, 2004), and the static magnetic-field levels are likewise well below International Commission on Non-Ionizing Radiation Protection (ICNIRP) and Food and Drug Administration guidelines (FDA, 2014; ICNIRP, 2009) for static magnetic-field exposure.

Space Charge

Neither the federal government nor the state of Maine has standards or guidelines for ion density associated with transmission lines. The calculated ion densities outside the ROW of the DC-only and combined DC+AC segments are within the range of levels otherwise encountered in the environment.

AC Electric and Magnetic Fields

The AC transmission lines will produce 60-Hz AC electric and magnetic fields that are calculated to be below assessment criteria established by ICNIRP and the International Committee on Electromagnetic Safety, which provide guidelines on public exposure and AC electric-field levels on transmission line ROWs (ICES, 2002; ICNIRP, 2010).

Note that this Executive Summary does not contain all of Exponent's technical evaluations, analyses, conclusions, and recommendations. Hence, the main body of this report is at all times the controlling document.

Introduction

Central Maine Power Company (CMP) has proposed the New England Clean Energy Connect (NECEC) project to deliver electricity to Maine over an approximately 145.3-mile ±320-kilovolt (kV) direct current (DC) transmission line (Section 3006) from the Québec-Maine border at Beattie Township to the proposed Merrill Road Converter Station in Lewiston. A 345-kV alternating current (AC) transmission line (Section 3007) approximately 1.6 miles long will connect Merrill Road Converter Station to the existing Larrabee Road Substation in Lewiston. The DC portion of the NECEC project will be located partially within undeveloped existing transmission corridors and partially within an undeveloped corridor primarily traversing industrial forest land. To accommodate the additional power coming into Maine, a new 26.5 mile 345-kV AC line (Section 3027) will be located in an existing corridor adjacent to Section 392, a 345-kV transmission line. Section 68, a 115 kV transmission line, also occupies the corridor for most of the distance between the two substations. Several other lines enter or exit the corridor at the substation approaches, but these two transmission lines define the majority of the corridor. Finally, two existing 115-kV AC transmission lines (Sections 64 and 62) will be rebuilt on single pole structures in the 16-mile corridor between the Larrabee Road Substation and the Surowiec Substation.[3] Over the majority of the route, the NECEC project is planned to be constructed on existing transmission corridors.

This report evaluates the effect of the proposed DC transmission lines on existing levels of static electric and magnetic fields and ion densities, the effect of the upgrades to the AC transmission lines on 60-Hertz (Hz) electric and magnetic fields during operation of all lines to assess compliance with applicable standards and guidelines.

Route Description

The NECEC project includes existing and proposed transmission lines of different voltages and configurations. The route segments are grouped in three general configurations:

[3] Section 62 will be rebuilt in only 9.3 miles of this 16-mile corridor between Crowleys Substation and the Surowiec Substation.

1. **DC-Only–**This configuration will contain proposed Section 3006, an overhead ±320-kV DC transmission line on a new right of way (ROW).
2. **DC+AC–**This configuration will contain the proposed Section 3006 (overhead ±320-kV DC) adjacent to existing 115-kV transmission lines.
3. **AC-Only**–The AC-only configurations will contain:
    a. Proposed Section 3007, a 345-kV interconnection from Merrill Road Converter Station to Larrabee Substation.
    b. Proposed Section 3027, a 345-kV transmission line adjacent to existing 34.5/115/345-kV transmission lines.
    c. Rebuilt Sections 64 and 62, 115 kV transmission lines and other very short segments.

The routes are categorized in this way because the assessment criteria, calculation methods and results vary among these three configurations. The segments can also be categorized geographically for discussion of each of the three separate transmission line routes. Figure 1 shows the locations of transmission line segments for the NECEC project. Section 3006 is proposed to be constructed between the Québec-Maine border and the proposed Merrill Road Converter Station near Larrabee Road Substation along the route marked by the green line in Figure 1. This route of Section 3006 contains one DC-only segment and several DC+AC segments. The route of proposed Section 3027 contains only AC lines and is marked by the purple line between Coopers Mills Substation and Maine Yankee Substation. The route of rebuilt Sections 64 and 62 also contains only AC lines and is marked by the orange line between Larrabee Road Substation and Surowiec Substation. The blue lines in the figure indicate the routes of nearby existing 345-kV lines.

Figure 1. NECEC project transmission line routes.

The segments of the NECEC project are described in Table 1 by cross-section (XS) number, reference to exhibit sheet, the length of the segments, transmission line numbers, and voltages. Cross sections are separated between the three project routes: XS-1 through XS-7 are DC-only and DC+AC cross sections located along the route of Section 3006, XS-8 through XS-15 are

AC-only cross sections located along the route of Section 3027, and XS-16 through XS-28 are AC-only cross sections located along the route of Sections 62 and 64. These lines are shown on key maps and sheets included as Exhibit NECEC-8 to the Petition. These cross sections were identified for modeling of all unique line configurations associated with the project. Some segments were excluded because of their short length and distance to nearest viewable residence.

Table 1. Project route segments

XS	Sheets*	Distances (miles)	DC Sections (Voltage)	AC Sections (Voltage)
DC Section 3006 Route				
1	NECEC-1	53.5	3006 (± 320 kV)	n/a
2	NECEC-2,4	15.2, 5.5	3006 (± 320 kV)	222 (115 kV)
3	NECEC-5	19.8	3006 (± 320 kV)	63 (115 kV)
4	NECEC-8	25.2	3006 (± 320 kV)	278 (115 kV)
5	NECEC-9	1.1	3006 (± 320 kV)	278 (115 kV), 243A (115 kV), 89 (115 kV)
6	NECEC-10,11,12,14	0.3, 0.1, 4.2, 17.8	3006 (± 320 kV)	251 (115 kV), 200 (115 kV)
7	NECEC-13	0.8	3006 (± 320 kV)	251 (115 kV), 200 (115 kV)
AC Section 3027 Route				
8	S5-3	0.4	n/a	3027 (345 kV), 377 (345 kV), 375 (345 kV), 392 (345 kV), 378 (345 kV), 207A (115 kV)
9	S5-4	1.7	n/a	3027 (345 kV), 377 (345 kV), 375 (345 kV), 392 (345 kV), 207A (115 kV)
10	S5-5	1.6	n/a	3027 (345 kV), 392 (345 kV)
11	S5-6	1.4	n/a	3027 (345 kV), 392 (345 kV), 68 (115 kV), 204 (115 kV), 25 (34.5 kV)
12	S5-7	0.3	n/a	3027 (345 kV), 392 (345 kV), 68 (115 kV), 204 (115 kV)
13	S5-8	1.8	n/a	3027 (345 kV), 392 (345 kV), 68 (115 kV), 204 (115 kV)
14	S5-9	17.2	n/a	3027 (345 kV), 392 (345 kV), 68 (115 kV)
15	S5-10	0.3	n/a	3027 (345 kV), 392 (345 kV), 68 (115 kV)
AC Sections 62, 64 Route				
16	S4-1	0.35	n/a	64 (115 kV), 212 (115 kV), 251 (115 kV), 201 (115 kV), 3026 (345 kV), 72 (34.5 kV)
17	S4-2	1.96	n/a	64 (115 kV), 76 (34.5 kV), 201 (115 kV), 3026 (345 kV)
18	S4-3	0.27	n/a	64 (115 kV), 76 (34.5 kV), 201 (115 kV), 3026 (345 kV)
19	S4-4	0.31	n/a	64 (115 kV), 76 (34.5 kV), 201 (115 kV), 3026 (345 kV)
20	S4-5,7	0.67, 0.15	n/a	64 (115 kV), 76 (34.5 kV), 201 (115 kV), 3026 (345 kV)
21	S4-6	0.37	n/a	64 (115 kV), 76 (34.5 kV), 201 (115 kV), 3026 (345 kV)
22	S4-9	1.25	n/a	64 (115 kV), 201 (115 kV), 3026 (345 kV)

XS	Sheets*	Distances (miles)	DC Sections (Voltage)	AC Sections (Voltage)
23	S4-10	1.0	n/a	64 (115 kV), 201 (115 kV), 3026 (345 kV)
24	S4-11	1.1	n/a	64 (115 kV), 62 (115 kV), 3026 (345 kV)
25	S4-12	1.57	n/a	64 (115 kV), 62 (115 kV), 3026 (345 kV)
26	S4-13	0.34	n/a	64 (115 kV), 62 (115 kV), 3026 (345 kV)
27	S4-14	5.7	n/a	64 (115 kV), 62 (115 kV), 3026 (345 kV)
28	S4-15	0.56	n/a	64 (115 kV), 62 (115 kV), 3026 (345 kV)
Excluded Segments				
n/a	NECEC-3	1.1	3006 (± 320 kV)	222 (115 kV)
n/a	NECEC-6	0.2	3006 (± 320 kV)	279 (115 kV), 63 (115 kV)
n/a	NECEC-7	0.2	3006 (± 320 kV)	279 (115 kV), 63 (115 kV)
n/a	NECEC-15	0.3	3006 (± 320 kV)	251 (115 kV), 200 (115 kV)
n/a	NECEC-16	1.6	n/a	3007 (345 kV AC), 251 (115 kV), 200 (115 kV)
n/a	S5-1	0.5	n/a	3027 (345 kV), 377 (345 kV), 375 (345 kV), 392 (345 kV), 378 (345 kV)
n/a	S5-2	0.4	n/a	3027 (345 kV), 377 (345 kV), 375 (345 kV), 392 (345 kV), 378 (345 kV)
n/a	S5-11	0.9	n/a	3027 (345 kV), 3025 (345 kV), 392 (345 kV), 88 (115 kV), 60 (115 kV), 68 (115 kV), 80 (115 kV), 49 (34.5 kV)
n/a	S4-8	0.51	n/a	64 (115 kV), 201 (115 kV), 3026 (345 kV)

*Sheet names refer to those included in Exhibit NECEC-8 of the Petition.

DC-Only Transmission Line Segments

The initial northern portion of the DC transmission line (Section 3006) from the Canadian border will be an overhead line in a horizontal configuration on a new transmission line ROW that runs for approximately 53.5 miles, as shown in Figure 2 (Segment NECEC-1). Section 3006 then joins an existing AC transmission ROW (Segment NECEC-2) near The Forks.

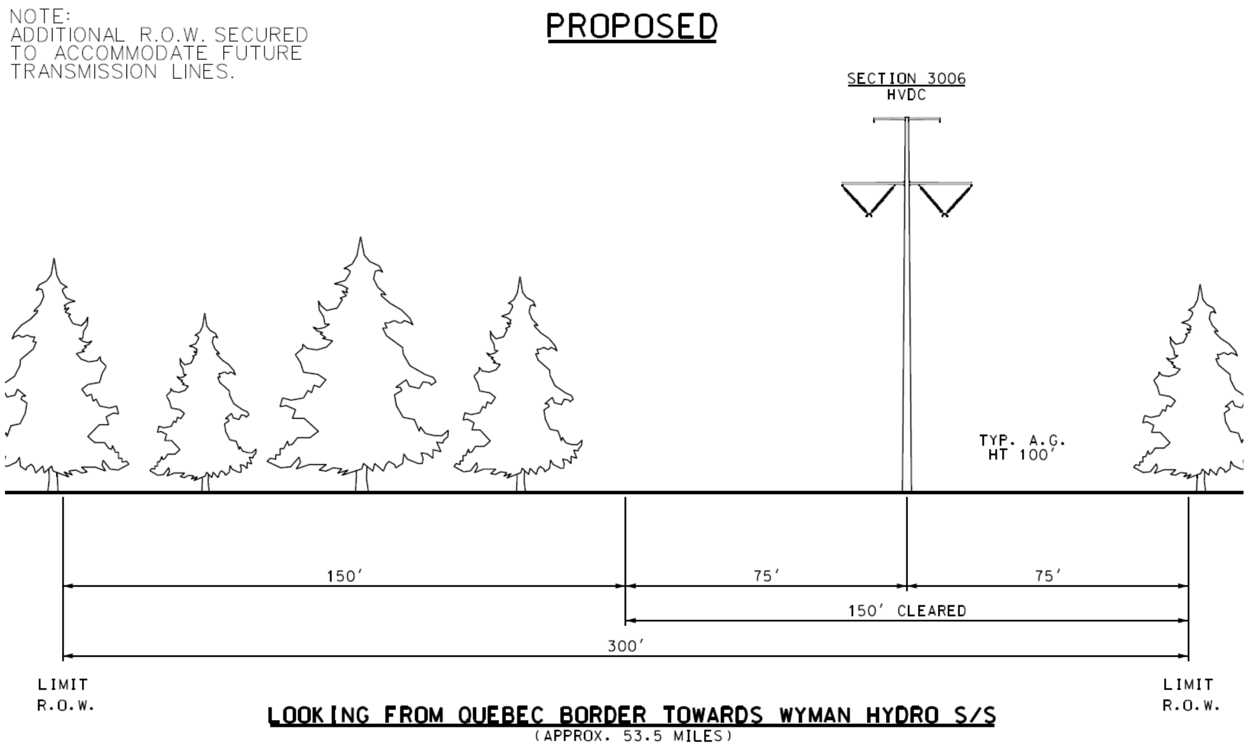

Figure 2. Example of DC-Only Segment NECEC-1 (XS-1) of the transmission line ROW.

Segment NECEC-1 contains the proposed (±320-kV) transmission line on a 300-foot ROW.

Combined DC+AC Transmission Line Segments

As described in greater detail throughout the rest of this report, the calculations and assessment of AC and DC transmission lines have many similarities, but ultimately, are evaluated according to different criteria. This is particularly true for route segments where both DC and AC transmission lines are present on the same ROW. Combined DC+AC configurations describe 91.8 miles of the route where the DC line is proposed to be constructed adjacent to existing AC lines of various voltages and configurations. An example of a combined DC+AC ROW planned for the longest segment of the route (NECEC-8, 25.2 miles) is shown in Figure 3.

The DC line terminates at the proposed Merrill Road Converter Station in Lewiston. Here DC electricity on the DC line is converted to AC electricity before connecting to the Maine AC transmission system at the Larrabee Road Substation in Lewiston.

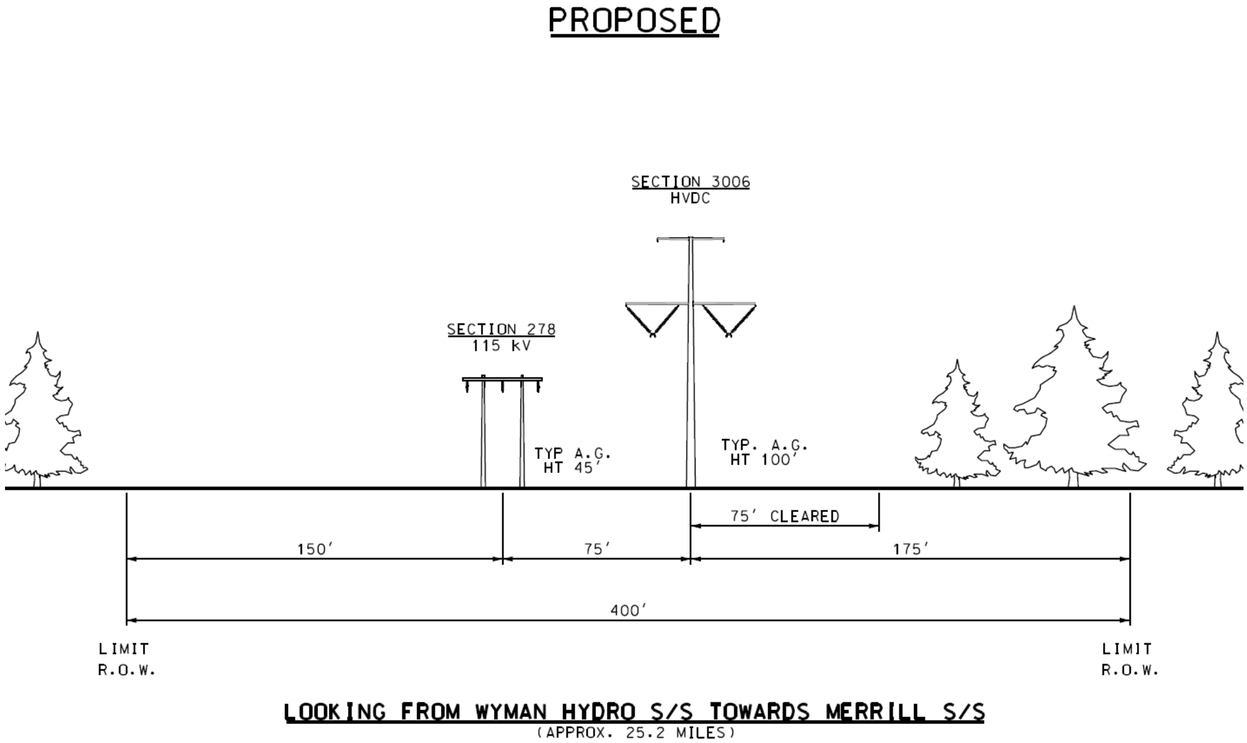

Figure 3. Example of a combined DC+AC segment of the transmission line ROW (NECEC-8; XS-4).

Segment NECEC-8 contains the proposed (±320-kV) Section 3006 on a 400-foot ROW alongside existing 115-kV AC Section 278.

AC-Only Transmission Line Segments

The first of the AC-only transmission line segments of the project starts at the proposed Merrill Road Converter Station.[4] A 1.6 mile 345-kV AC interconnection, to be known as Section 3007, will connect Merrill Road Converter Station to the existing Larrabee Road Substation in Lewiston. This segment is excluded from calculations due to its short distance and distance to nearest viewable residence.

To accommodate the extra power supplied to the Maine transmission system over the DC line, new 345-kV AC Section 3027 between the Coopers Mills Road Substation in Windsor, and the

[4] Converter terminals and substations are not discussed separately because the highest levels of AC electric and magnetic fields at the boundary will likely be from the transmission lines where they enter these facilities (IEEE Std. 1127-2013).

Maine Yankee Substation in Wiscasset, will be located on an existing 26.5-mile long ROW that includes Section 392, a 345-kV transmission line. Section 68, a 115-kV transmission line also occupies the corridor for most of the distance between the two substations. Several other lines enter or exit the corridor at the substations' approaches, but these two lines define the majority of the corridor. Segment S5-9 (XS-14) is the longest segment between these substations (17.2 miles) and so this segment is shown as an example of this project route in Figure 4 below.

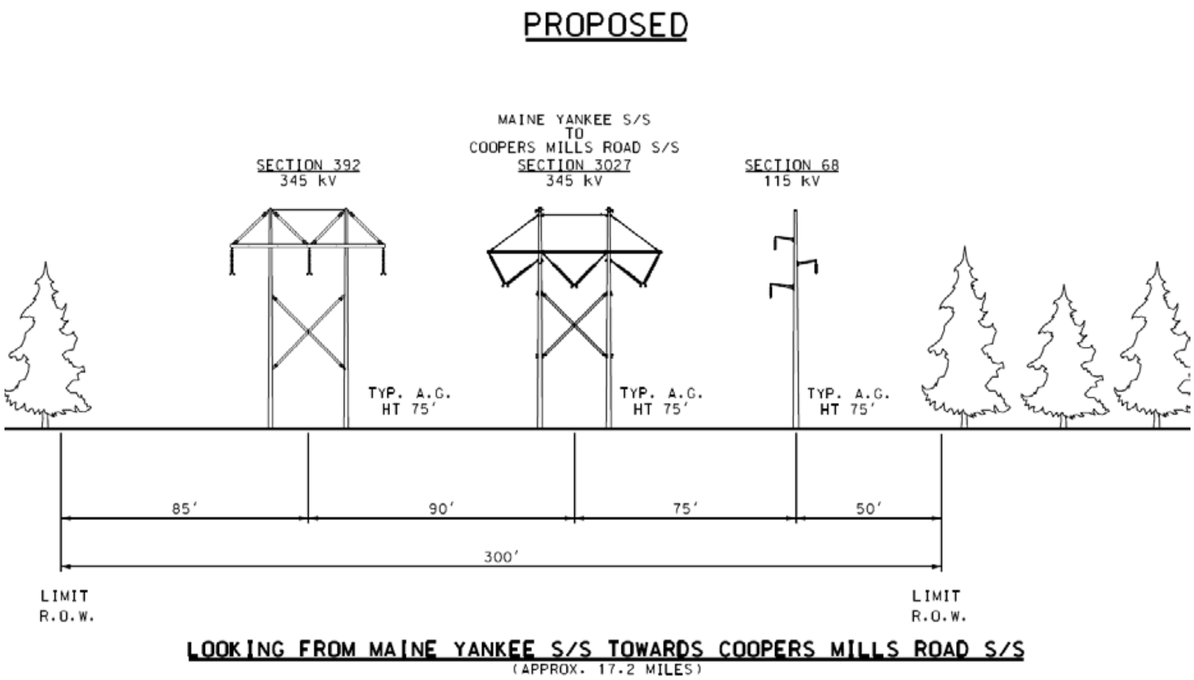

Figure 4. Example of an AC-only segment of the transmission line ROW (S5-9; XS-14) along the proposed route of Section 3027.

Segment S5-9 contains the proposed 345-kV Section 3027, existing 345-kV Section 392, and existing 115-kV Section 68 on an existing 300-foot ROW.

The two existing 115-kV AC transmission Sections 64 and 62 will be rebuilt on single pole structures in the 16-mile corridor between the Larrabee Road Substation and the Surowiec Substation. The longest segment of this route (S4-14; XS-27, 5.7 miles) is shown as an example in Figure 5 below.

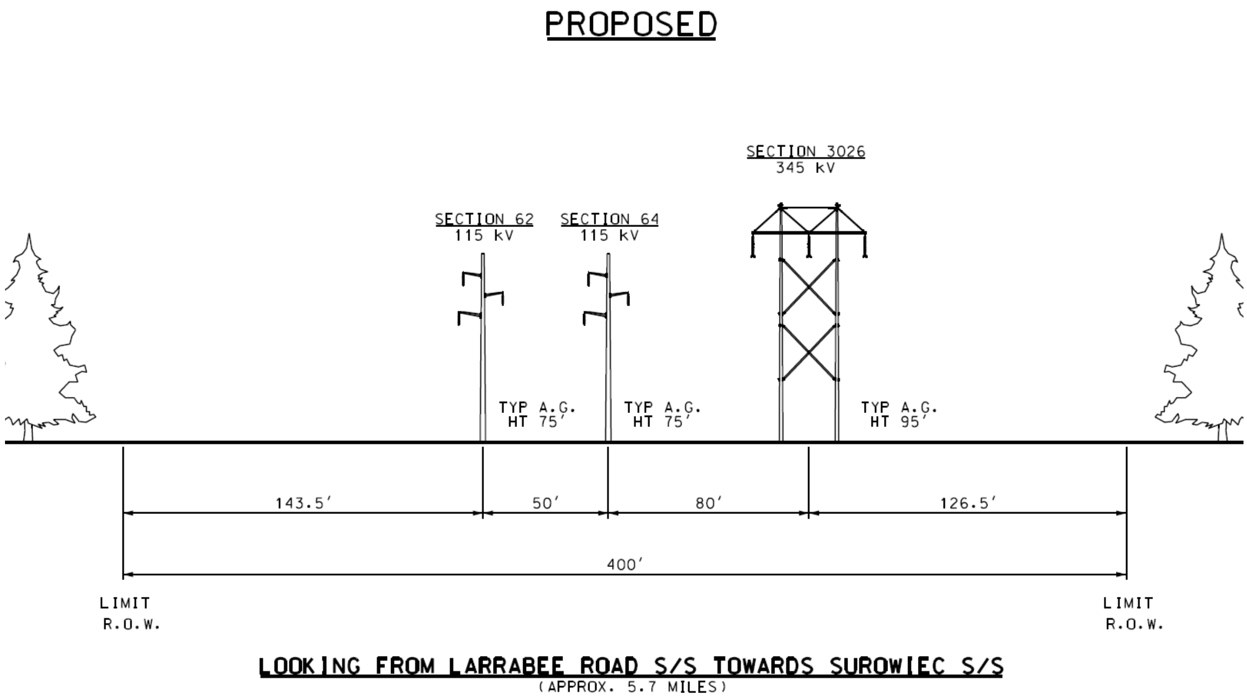

Figure 5. Example of an AC-only segment of the transmission line ROW (S4-14; XS-27) along the route of Sections 62 and 64.

Segment S4-14 contains the 115-kV Sections 62 and 64, and existing 345-kV Section 3026 on an existing 400-foot ROW.

Environmental Conditions and Assessment Criteria

DC Line Electrical Environment

The electrical environment associated with a DC transmission line is characterized by static electric fields, static magnetic fields, and corona phenomena. Static electric fields and magnetic fields vary little over time, and thus have a frequency of ~0 Hz.[5] Corona on the conductors is the source of space charge.[6] The strength (i.e., the level) of the fields and corona diminish quickly with distance from the line.

Static Electric Fields

Static electric fields are natural phenomena that arise from various sources. A commonly encountered source of a static electric field is friction charging that creates static electricity (i.e., charge separation) and is experienced as "carpet shocks." Another source of static electric fields is from atmospheric conditions such as thunder (electrical) storms. Man-made static electric fields result from voltage applied to electrical conductors and equipment that operate on DC power. Electric fields are measured in units of volts per meter (V/m) or kilovolts per meter (kV/m), where 1 kV/m is equivalent to 1,000 V/m. The local electric fields associated with carpet shocks can reach 100 kV/m or higher and up to 500 kV/m from clothing. The naturally occurring atmospheric electric field ranges between 120-150 V/m on a clear day, but can increase to as high as 40 kV/m or higher beneath an active thunderstorm. Electric fields are easily shielded or attenuated by most conducting objects such as fences, shrubbery, and buildings, so outdoor sources, such as transmission lines contribute little to indoor electric-field levels.

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[5] The power on a DC line is carried as a direct current and so is a source of static fields. Negligible time-varying fields can occur that may not have been entirely filtered out at the converter station. In comparison, AC transmission lines produce time-varying fields with a frequency of 60-Hz but no static fields.

[6] Corona also can be a source of audible and radio noise. Radio noise can interfere with the reception of amplitude-modulated radio signals on or very close to the ROW. The reception of frequency-modulated radio signals and digital TV signals is typically not affected during normal operation. Trace quantities of ozone and nitrous oxides also can be produced during certain conditions but are too small to affect ambient levels.

Static Magnetic Fields

Static magnetic fields are also natural phenomena produced by the flow of electric currents. The Earth produces a background geomagnetic field that originates from the electrical currents in the Earth's molten core and crustal sources. The geomagnetic field varies with latitude; it is highest at the magnetic poles and lowest at the equator (~700 and ~200 milligauss [mG], respectively). Man-made static magnetic fields result from a number of sources: battery-powered appliances and toys, kitchen magnets, magnetic resonance imaging scanners, electrified railways, and DC transmission lines, to name a few. Magnetic fields are calculated as magnetic flux density measured in units of Tesla or microtesla according to the International System of Units, or in units of Gauss (G) or mG, where 1 microtesla = 10 mG. In this report, units of mG or G are used. Since magnetic fields are vectors characterized by magnitude and direction, magnetic fields from a DC transmission line add to or subtract from the Earth's geomagnetic field depending on the orientation of the line with respect to Earth's geomagnetic field. Unlike electric fields, magnetic fields are not easily shielded or attenuated by most conducting objects.

Corona Phenomena (Space Charge)

Corona occurs around the conductors of DC transmission lines when the electric field at conductor surfaces exceeds the insulating capacity of the surrounding air. The electric field surrounding transmission-line conductors becomes concentrated on surface irregularities such as nicks, debris, insects, or water droplets and causes the electrical breakdown of air around these points resulting in a small electrical discharge into the air. When this occurs on a transmission line, a tiny amount of energy is released and the transmission line is considered to be in corona. Transmission lines are designed so that ideally they would produce minimal corona. The presence of water droplets, insects, nicks, debris, or other surface roughness on the conductor, however, can initiate corona, which makes transmission line corona a weather- and seasonal-dependent phenomenon. Corona activity on transmission lines varies in time due to variations in the conductor environment as described above. Corona generated phenomena including space charge and the static electric field contributed by space charge can vary in time due to variations in the environment and therefore are reported in statistical terms as the median level or L_{50} exceedance level.

Space charge is a collective term for small air ions and large air ions (i.e., charged aerosols) that are present everywhere in our environment from both natural and man-made sources. Air ions and charged aerosols can be created at the surface of transmission lines when the lines are in corona. Natural sources include space charge formed in the Earth's atmosphere by weather events such as frictional breakup of particles created by blowing precipitation or dust, and evaporation or water droplet breakup, such as from waterfalls. Boiling water in a tea kettle or running a shower can also produce space charge. Space charge levels from these sources can range from hundreds to many thousands of ions per cubic centimeter (ions/cm^3). Other sources of space charge commonly encountered are open flames from candles or gas ranges. These can produce general levels of space charge in the range of a thousand to tens of thousands ions/cm^3.

DC Line Environmental Assessment Criteria

The DC transmission line proposed as part of the NECEC project is a 145.3-mile ±320-kV line from the Québec-Maine border at Beattie Township to the proposed Merrill Road Converter Station in Lewiston. Several scientific and governmental agencies have established guidelines for exposure to static electric and magnetic fields, including the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the Food and Drug Administration (FDA). The National Radiological Protection Board of Great Britain (NRPB) has noted a threshold value for human perception, which is not a guideline. The values listed in Table 2 are used as criteria for the evaluation of the DC line on the surrounding electrical environment.

Table 2. Environmental assessment standards and guidelines for static fields

Electrical Parameter	Limit	Agency providing guideline (year)	Comment
Static electric field	25 kV/m	NRPB (2004)	Threshold value above which annoying perceptions may occur
Static magnetic field	4,000 G	ICNIRP (2009)	Continuous exposure of the general public
	40,000 G (infants) 80,000 G (adults)	FDA (2014)	Patient MRI exposure
Space charge*	-	-	No health guideline proposed

* No scientific or regulatory agency has determined that small air ions, ion current density, or charged aerosols pose a threat to the environment or to human health, so no exposure guidelines have been proposed. The Ministry of Health of the Russian Federation, however, recommended that positive and negative air ion levels be maintained between a minimum of 400 ions/cm^3 and a maximum of 50,000 ions/cm^3 for public and industrial quarters (MHRF, 2003). The scientific basis for determining the guideline levels was not described.

AC Line Electrical Environment

The AC transmission lines proposed as part of the NECEC project include the 1.6 mile interconnection Section 3007 from the proposed Merrill Road Converter Station to the Larrabee Substation, the new 26.5 mile 345-kV AC Section 3027 between the Coopers Mills Road Substation in Windsor and the Maine Yankee Substation in Wiscasset, the rebuilt 115-kV Section 64 that traverses the 16.1 mile corridor between the Larrabee Road Substation and the Surowiec Substation, and the rebuilt 115-kV Section 62 that shares the ROW with Section 64 for 9.3 miles between Crowley's Substation and the Surowiec Substation.

AC electric and magnetic fields are associated with any electrical source that generates, transmits, or uses electricity. All things connected to our electrical system—power lines; wiring in our homes, businesses, and schools; and all electric appliances and machines—are a source of AC electric and magnetic fields because, in North America, the vast majority of electricity is transmitted as AC at a frequency of 60 Hz. The fields from these AC sources are commonly referred to as power-frequency or extremely low frequency electric and magnetic fields.

AC Magnetic Fields

The current flowing in the conductors of a transmission line generates a magnetic field near the transmission line. AC magnetic fields measurements are typically expressed as magnetic flux density in units of G or mG, where 1 G is equal to 1,000 mG. In contrast to electric fields, the strength of a magnetic field is unaffected by the voltage of the conductor, but is determined primarily by the amount of current flowing in the conductor, so the magnetic-field level can change depending upon the patterns of power demand (load) on the bulk transmission system. To address this variability, modeling results are presented for average and peak line loading conditions.

AC Electric Fields

Electric fields are due to voltage on conductors not the current carried on them, so electric fields are present around conductors of any voltage. Unlike magnetic fields, electric-field levels do not change with increased or decreased load (current) on transmission-line conductors.

AC electric fields are expressed in units of V/m or kV/m, where 1 kV/m is equal to 1,000 V/m. The strength of an electric field at any location is determined by voltage applied to any nearby (unshielded) electrical equipment as well as the distance to the equipment, but is unaffected by the amount of current flow in the device. As mentioned, electric-field levels will not vary with changes in current, but will be lower near a low voltage source than near a high voltage source; in both cases, the field level will decrease with increasing distance from the source. Electric fields are effectively shielded by conducting objects such as trees, fences, and buildings.

Corona Phenomena

As described above in conjunction with the DC transmission line, corona refers to the partial electrical breakdown of the air surrounding conductors. In contrast to DC transmission lines, however, corona on AC transmission-line conductors results in minimal space charge around the line because the voltage of an AC conductor is constantly changing from positive to negative in a cycle that repeats 60 times per second (60 Hz). Positively-charged air ions produced by corona during the positive half cycle of the voltage are attracted back towards the conductor during the negative half cycle where they are neutralized (i.e., removed from the air) due to the reversed direction of the electric field. The same phenomenon occurs with negatively-charged air ions produced during the negative half cycle. Unlike corona activity on a DC line, space charge around an AC line does not add to the electric field created by the transmission conductors.

AC Line Environmental Assessment Criteria

Similar to DC transmission lines, AC transmission lines also affect the ambient electrical environment and can be assessed in terms of standards and guidelines developed by scientific and health agencies. Several agencies have published exposure limits to 60-Hz electric and magnetic fields, including the International Committee on Electromagnetic Safety (ICES) and ICNIRP. AC transmission lines create electric fields and magnetic fields that vary in time differently than DC transmission lines and are therefore compared to different standards than DC lines.

ICNIRP and ICES each specify both Basic Restrictions (the prescribed limits on internal body exposure) and reference levels for the environments of the general public and workers with 60-Hz electric and magnetic fields that can be measured or calculated to assure compliance with the Basic Restrictions. Basic Restrictions limit the maximum recommended electric fields induced *in body*. Since levels of electric fields induced in tissues are difficult to measure, reference levels are provided as test values to ensure that basic restrictions are not exceeded. In the cases where reference levels are exceeded, both ICES and ICNIRP note that further analyses and computations are needed to demonstrate compliance with Basic Restrictions. In this report, exposures expected to produce internal electric fields equal to the Basic Restrictions were derived by applying mathematical modeling described by Kavet et al. (2012). The values listed in Table 3 are used as criteria for the evaluation of proposed AC transmission lines on the existing electrical environment.

Table 3. Guidelines for environmental assessment of AC fields from AC transmission lines

Electrical Parameter	Limit*	Agency Providing Guideline (Year)	Comment
AC electric field	4.2 (36.4) kV/m	ICNIRP (2010)	General public exposure
	5.0 (26.8) kV/m†	ICES (2002)	
AC magnetic field	2,000 (12,400) mG	ICNIRP (2010)	General public exposure
	9,040 (9,150) mG	ICES (2002)	

* For electric fields and magnetic fields, both reference levels and Basic Restrictions are shown. Reference levels quoted from the respective standard are listed first; the limits (i.e., Basic Restrictions) derived by mathematical modeling described by Kavet et al. (2012) at 60 Hz are shown in parenthesis.

† There is an exception within transmission line ROWs, where the limit is 10 kV/m, because people do not spend a substantial amount of time in ROWs and very specific conditions are needed before a response is likely to occur (i.e., a person must be well insulated from ground and must contact a grounded conductor) (ICES, 2002, p. 27).

Calculation Methods

DC Transmission Line

The NECEC DC transmission line will operate with two conductor bundles (i.e., bipoles) at a nominal voltage of ±320 kV. Transmission line loading, conductor bundle configuration, conductor diameter, mid-span conductor height, conductor sag, conductor separation, and altitude were provided by CMP to Exponent for modeling.

The formulae and empirical curves used to calculate the static electric fields, magnetic fields, and air ions associated with the operation of the DC portion of the NECEC project were developed at the Electric Power Research Institute's (EPRI) High Voltage Transmission Research Center and formalized in the EPRI TL Workstation (EPRI 1990, 1991). Measurements from reduced scale DC models and full scale DC test lines in the northeastern United States form the developmental basis for these algorithms (Comber and Johnson, 1982; Johnson, 1983; Carter and Johnson, 1988; EPRI, 1990). The static field and air ion calculations are based on a saturated corona model and then fitted to describe the performance of a DC transmission line under various climatic and operational conditions. It should be recognized that the parameters calculated by this program represent descriptors of statistical distributions that are strongly affected by weather and season.

The static electric fields, static magnetic fields, and ion densities associated with the proposed configurations of the DC line segments were calculated along profiles perpendicular to mid-span where the conductor height above ground is lowest (29 feet) out to a distance of 200 feet beyond each edge of the ROW. Static magnetic fields, static electric fields, and ion densities were calculated at a height of 1 meter above ground, according to IEEE Standard 644-1994 (IEEE, 1994, R2008). The altitude used in modeling each DC segment was selected based upon the highest altitude found along that segment, which ranged from 317 feet above sea level near Livermore to a maximum of 2,683 feet near the border with Canada for the DC and combined DC+AC segments.

Since the intensity of corona varies depending on variable factors (e.g., weather and season), static electric fields and space charge are variable over time, and the calculated values were summarized by the median (i.e., L_{50}) value. The DC line was modeled with constant conductor polarity and a 1% overvoltage. To maximize computed values, calculations for the DC line were performed for hot, humid summer conditions, with no wind. This set of weather conditions results in the highest levels of calculated parameters in fair weather since drier weather, some wind, or lower altitude can result in lower levels of static electric fields and ion densities. These levels also change with the occurrence of foul weather so calculations were also performed to describe the performance of the line under this condition as well.

AC Transmission Lines

Many of the basic assumptions and general methodology for calculating electric fields and magnetic fields for AC transmission lines, although similar in concept to those for DC transmission lines, require different computation routines. Calculation of the AC electric and magnetic fields for the AC-only and DC+AC segments were performed using algorithms developed specifically for AC transmission lines by the Bonneville Power Administration (BPA), an agency of the U.S. Department of Energy (BPA, 1991).

Each transmission-line conductor was modeled as infinite in length and parallel to one another at a fixed distance above an infinite flat Earth. A 5% overvoltage was assumed for all the AC transmission lines. These assumptions are made to make the calculations more tractable and to ensure that the presented values are representative of the highest field levels that might be encountered beneath the line.[7] Although these assumptions simplify the calculations, they have been shown to accurately predict electric-field and magnetic-field levels measured near transmission lines (Chartier and Dickson, 1990).

[7] There are variations in the transmission line clearance height above ground due to the sag of the transmission lines over variable-height terrain, but levels of electric and magnetic fields beneath the transmission lines will be lower where the clearance of the lines above ground is higher.

Modeling Configurations

Data for modeling the transmission lines provided by CMP included conductor configurations and existing and proposed transmission line loading. The magnitude of the magnetic field is proportional to loading, so magnetic-field levels were modeled for five separate load levels.

1. Post-project peak load on the DC line;
2. Pre-project average load on the AC lines;
3. Pre-project peak load on the AC lines;
4. Post-project average load on the AC lines; and,
5. Post-project peak load on the AC lines.

The load assumed for modeling of the magnetic field for any randomly selected day of the year is the average load. In contrast, the peak load was assumed to predict the highest magnetic fields that might occur only a few hours or days during the year. The DC line will operate almost continuously at full load, so average and peak load have been considered the same.

In contrast to magnetic-field levels, electric-field levels do not depend directly on loading and so are not modeled for separate loading scenarios.[8] The electric-field level is primarily determined by the conductor spacing, height above ground, and the voltage of the conductors. Electric-field levels were calculated for pre- and post-project configurations.

Where two separate AC transmission line circuits are located on the same ROW, the specific arrangement of the conductors on each structure will have an effect on the calculated levels of electric and magnetic fields. Therefore, Exponent performed a phase-optimization analysis, in which all possible phasing configurations of the new and rebuilt AC lines in each segment were analyzed. This analysis identified the particular phasing that reduced the highest AC magnetic-field level at either ROW edge to a minimum level considering the magnetic-field contributions of all the AC lines on the ROW. The identified optimal phasing for each new and rebuilt AC

[8] These parameters are associated with the electric field at the conductor surface, not current flow. The electric field is quite constant but the conductor height above ground will vary with loading and so will indirectly affect electric field levels. To account for this variation, all calculations of electric fields and magnetic fields are made at midspan for the lowest assumed conductor height under expected operating conditions.

line has been used for our analysis of each post-project configuration. Based on this analysis, CMP plans to implement these optimal phasings in their proposed design for the NECEC project. Phase optimization is one of the ways to minimize electric- and magnetic-field levels that is consistent with the recommendations of the WHO (2007).

Modeling Results

This section describes modeling results for analysis of the electrical environment around the proposed NECEC project. Static electric fields, magnetic fields, and ion densities are calculated for each cross section containing the DC line (XS-1 through XS-7), and AC electric and magnetic fields are calculated for each cross section containing an AC line (XS-2 through XS-28). Illustrative modeling results are described here, while complete summary tables and graphical profiles are provided in Appendices A through C:

- Appendix A – Summary tables of all modeling results
- Appendix B – Graphical profiles of calculated static fields and ion densities
- Appendix C – Graphical profiles of calculated AC electric and magnetic fields

Calculated Static Fields and Ion Densities

Static electric fields, static magnetic fields, and ion densities were calculated for each route segment containing DC Section 3006. The fields and ion densities arising from Section 3006 are described in cross sections XS-1 through XS-7. The proposed project route presently contains no DC lines, so pre-project levels of the DC-only-related quantities, except for the existing geomagnetic field, are estimated to be negligible.

Graphical profiles of the calculated post-project static electric-field levels in XS-1 are presented in Figure 6. Calculated results for fair weather are plotted in blue while results for foul weather are plotted in red. The profiles are plotted for view facing south along the proposed route with the eastern (−) and western (+) ROW edges marked. Negative values refer to the negative polarity of the static field and ion density. The only transmission line present in this cross section is Section 3006, positioned 75 feet from the western ROW edge. The positive polarity conductor is located closer to the center of ROW, near where the calculated static electric-field level in fair weather reaches its maximum magnitude of 17 kV/m. This field level decreases to −2.8 kV/m by the western edge of the ROW, and further decreases in magnitude to −0.6 kV/m by 100 feet beyond the edge of the ROW. Static electric-field magnitudes are calculated to be higher in foul weather, with a maximum magnitude of −23 kV/m decreasing to −6.6 kV/m by the edge of the ROW and −1.6 kV/m by 100 feet beyond the edge of the ROW. These data are summarized in Table 4 below, and calculated static electric-field levels for XS-1 through XS-7 are summarized in Table A-2 and Table A-3 of Appendix A. Graphical profiles are provided in Figure B-8 through Figure B-14 of Appendix B.

The magnitude of the calculated static electric-field level at the edge of the ROW is highest in XS-1. This is because the distance from Section 3006 to the nearest ROW edge is smallest (75 feet) in XS-1. In all other calculated cross sections, this distance is 150 feet or greater. The magnitude of the static magnetic-field levels and ion densities at edge of the ROW are also calculated to be highest in XS-1.

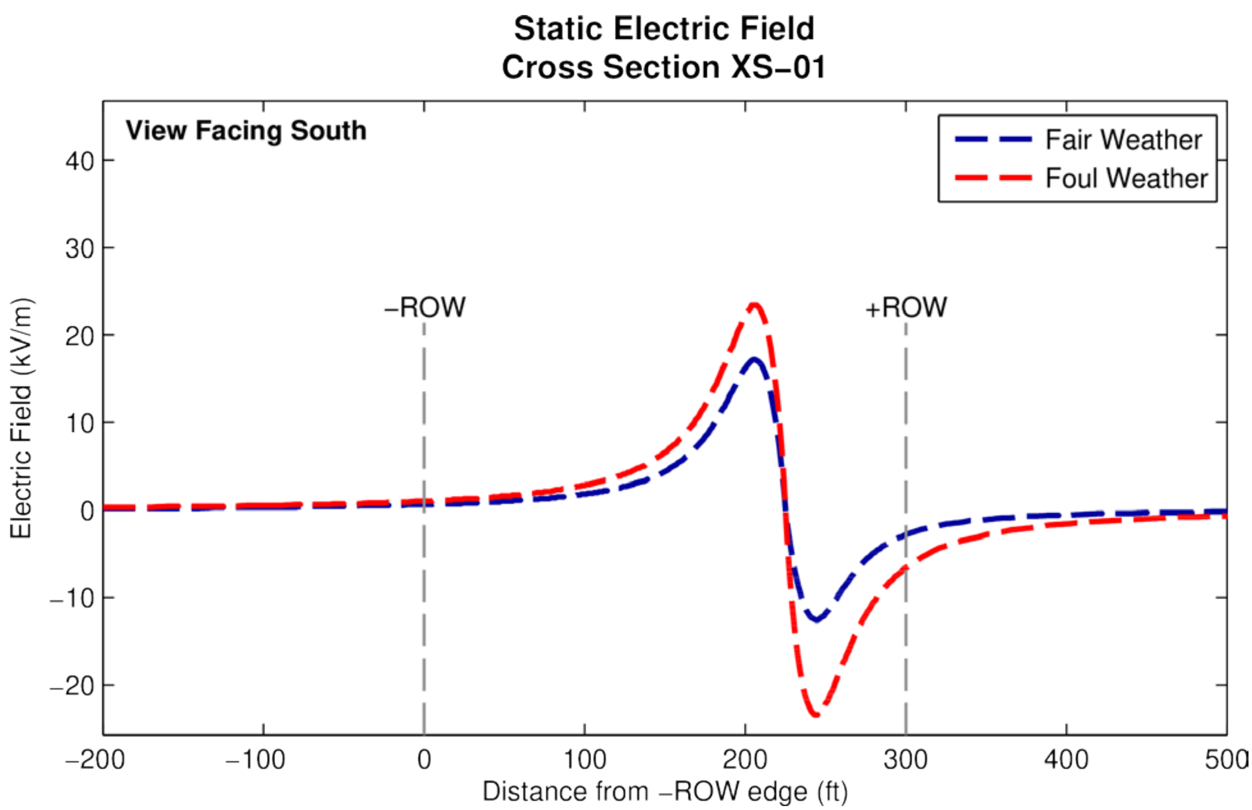

Figure 6. Calculated post-project static electric-field levels in XS-1.

A graphical profile of the calculated post-project static magnetic-field level in XS-1 is presented in Figure 7. The calculated field for just the DC line is shown in red, the geomagnetic field of

530 mG[9] is shown in orange, and the total combined field is shown in blue. This total magnetic field is what would be measured around the line after construction. The maximum total static magnetic-field level is 883 mG. The maximum calculated static magnetic-field level generated by the DC line is 359 mG, decreasing to 47 mG by the edge of the ROW. In all other cross sections (XS-2 through XS-7), the maximum calculated static magnetic-field level generated by the DC line is also 359 mG, but the calculated level at the edge of ROW, due to the DC line, is 13 mG or less due to the greater distance between Section 3006 and the ROW edge in those other segments of the route. Calculated static magnetic-field levels generated by the DC line for XS-1 through XS-7 are summarized in Table A-1 of Appendix A. Graphical profiles are provided in Figure B-1 through Figure B-7 of Appendix B.

[9] The geomagnetic field was calculated for a location near Wyman Hydro Substation in Moscow, Maine, using the World Magnetic Model calculator maintained by the National Oceanic and Atmospheric Administration. This location is approximately midway along the proposed route of Section 3006, and the geomagnetic field is estimated to vary by less than 2% over the length of this route.

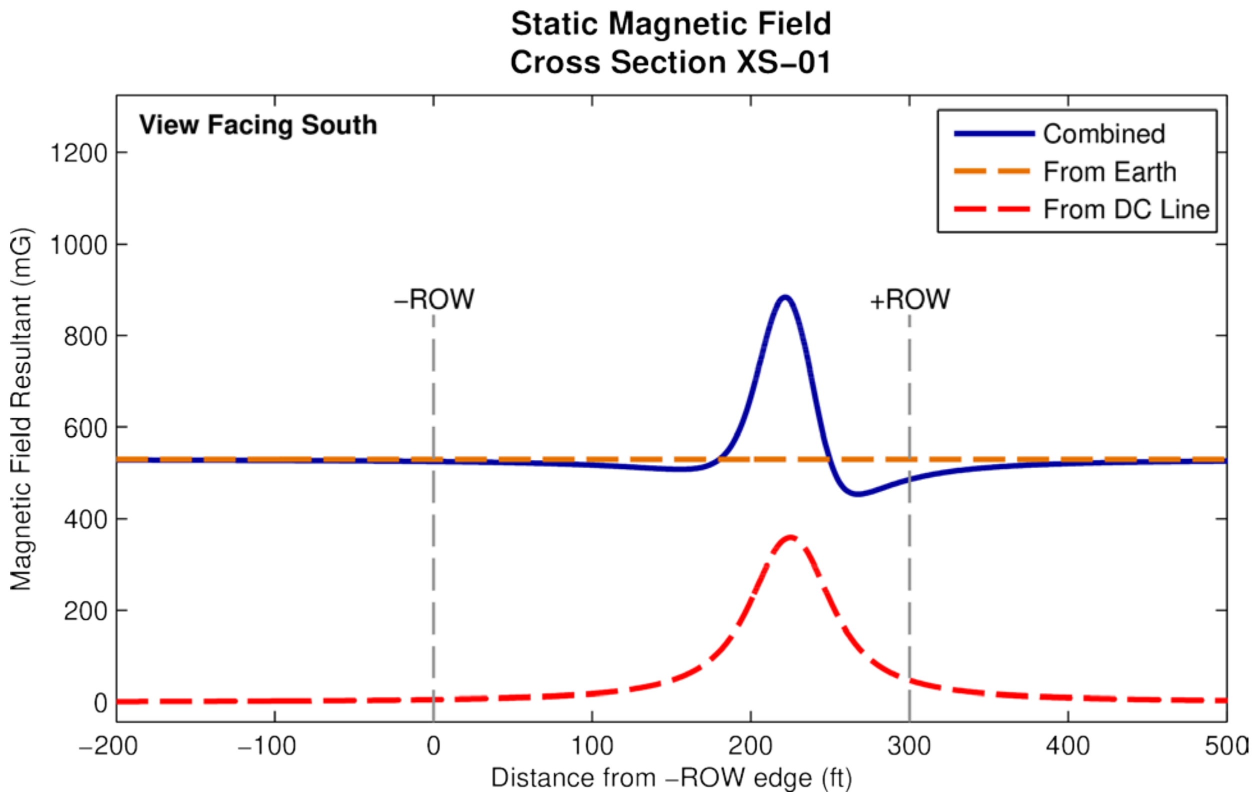

Figure 7. Calculated post-project static magnetic-field levels in XS-1.

Graphical profiles of the calculated post-project ion density levels in XS-1 are presented in Figure 8. Calculated results for fair weather are plotted in blue while results for foul weather are plotted in red. Negative values represent a density of negative ions. The maximum calculated magnitude on the ROW is 124,000 ions/cm^3 for fair weather, decreasing in magnitude to -13,600 ions/cm^3 by the edge of the ROW. In all other cross sections (XS-2 through XS-7), the maximum calculated magnitude is also approximately 124,000 ions/cm^3 near Section 3006, but the calculated level at the edge of the ROW is -2,700 ions/cm^3 or lower in magnitude due to the greater distance between Section 3006 and the ROW edge in those other segments of the route. Calculated ion densities for XS-1 through XS-7 are summarized in Table A-4 and Table A-5 of Appendix A. Graphical profiles are provided in Figure B-15 through Figure B-21 of Appendix B.

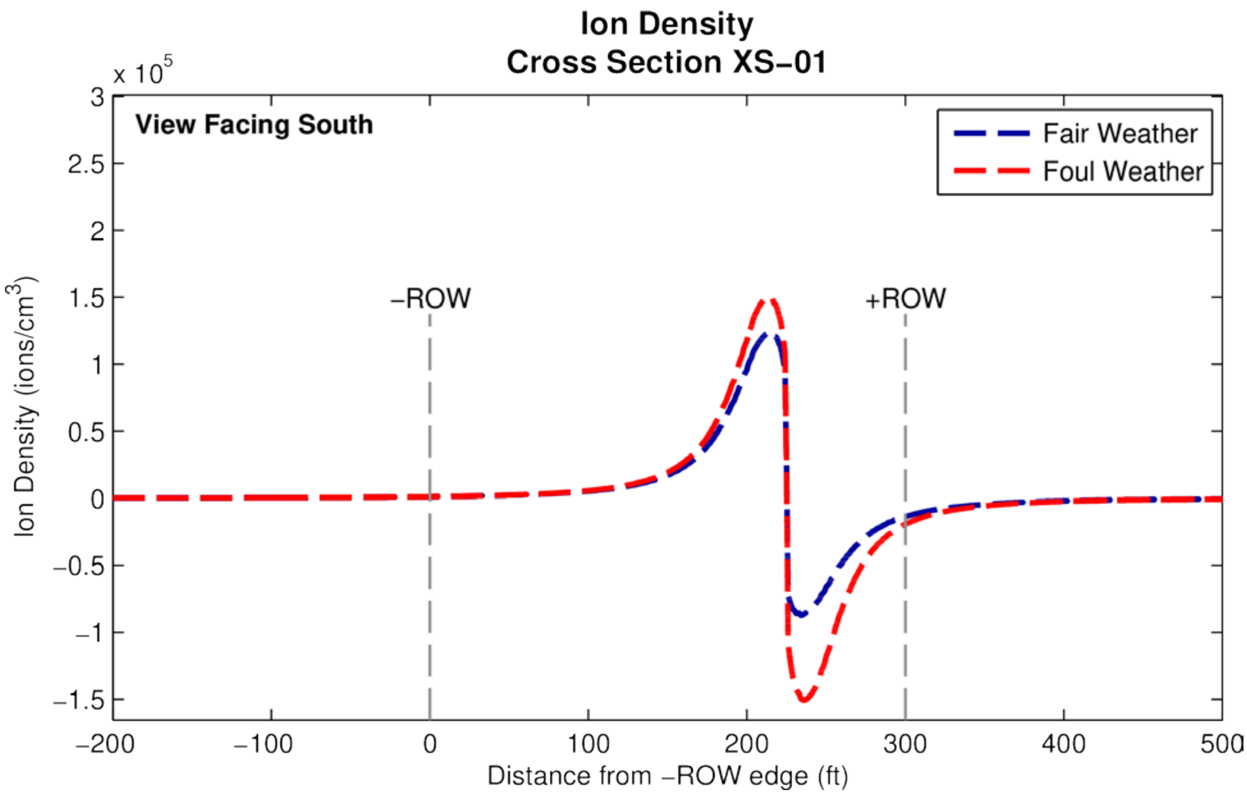

Figure 8. Calculated post-project ion density levels in XS-1.

Table 4 summarizes the calculated post-project static electric-field, magnetic-field, and ion density levels for XS-1. As described above, XS-1 contains the maximum calculated magnitude at the ROW edge for each of these DC-related electrical parameters due to the shorter distance between Section 3006 and the ROW edge in that cross section. This table provides a numerical summary of the graphical profiles that were presented above in Figure 6 through Figure 8.

Table 4. Summary of calculated post-project static electric-field, magnetic-field, and ion density levels for XS-1

	XS	100 feet beyond −ROW edge	−ROW edge	±Max on ROW	+ROW edge	100 feet beyond +ROW edge
Static Electric Field in Fair Weather (kV/m)	**1**	0.3	0.6	17	-2.8	-0.6
Static Electric Field in Foul Weather (kV/m)	**1**	0.5	1.0	23	-6.6	-1.6
Static Magnetic Field (mG)	**1**	2.8	5.7	359	47	9.4
Ion Density in Fair Weather (ions/cm^3)	**1**	400	1,100	124,000	-13,600	-2,000
Ion Density in Foul Weather (ions/cm^3)	**1**	410	1,200	151,000	-19,400	-2,300

Calculated AC Electric and Magnetic Fields

AC electric- and magnetic-field levels were calculated for each cross section that contains at least one AC line. This includes all cross sections except XS-1, which contains only proposed DC Section 3006. As there are many route segments that contain AC lines, calculated results are summarized here for the route of Section 3006 (XS-2 through XS-7), the route of Section 3027 (XS-8 through XS-15), and the route of Sections 62 and 64 (XS-16 through XS-28). Complete results for the calculated AC electric-field levels are summarized in Table A-8 of Appendix A, and graphical profiles for each cross section are provided in Figure C-28 through Figure C-54 of Appendix C. Complete results for the calculated AC magnetic-field levels are summarized in Table A-6 and Table A-7 of Appendix A for average and peak loading, respectively, and graphical profiles for each cross section are provided in Figure C-1 through Figure C-27 of Appendix C for average loading.

A brief summary of the calculated AC electric-field levels for selected cross-sections is provided in Table 5. For each project segment, the cross section containing the maximum calculated post-project value at the ROW edge was identified, and results for that cross section are included in the table below. Complete results for all cross sections are included in the appendices as described above. The maximum calculated post-project AC electric-field level at the ROW edge is 1.2 kV/m, occurring in XS-8 where the existing 345-kV Section 378 is located

85 feet from the + (eastern) ROW edge. This value of 1.2 kV/m is calculated to be 0.1 kV/m less than the pre-project value for that cross section. The maximum calculated post-project value at the ROW edge along the route of Section 3006 is 0.3 kV/m (in XS-6), and along the route of Sections 62 and 64 it is 1.1 kV/m (in XS-17 and XS-20). Each of these post-project levels is calculated to be very similar to pre-project levels. The maximum post-project AC electric-field level on the ROW is calculated to be 8.7 kV/m (similar to the pre-project maximum level of 8.1 kV/m), occurring in XS-10, XS-14, and XS-15,[10] where 345-kV Section 3027 is proposed to be constructed within 100 feet of existing 345-kV Section 392.

Table 5. Summary of calculated AC electric-field levels (kV/m) for selected cross sections

Project Segment	XS	Configuration	100 feet beyond −ROW edge	−ROW edge	Max on ROW	+ROW edge	100 feet beyond +ROW edge
Route of Section 3006 (XS-2 to XS-7)	**6**	Existing	< 0.1	0.3	1.6	< 0.1	< 0.1
		Proposed	< 0.1	0.3	1.6	< 0.1	< 0.1
Route of Section 3027 (XS-8 to XS-15)	**8**	Existing	< 0.1	0.1	8.1	1.3	0.2
		Proposed	< 0.1	0.1	8.4	1.2	0.2
Route of Sections 62, 64 (XS-16 to XS-28)	**20**	Existing	< 0.1	0.1	7.6	1.1	0.1
		Proposed	< 0.1	< 0.1	7.5	1.1	0.1

A brief summary of the calculated AC magnetic-field levels is provided in Table 6 for average loading. Again, only the cross sections containing maximum values at the ROW edge are shown. The maximum calculated post-project value at the ROW edge is 59 mG, occurring in XS-17 where the existing 345-kV Section 3026 is located 85 feet from the + (western) ROW edge. Similar levels are calculated for XS-20 where the line configurations are very similar to that of XS-17. The AC magnetic-field levels in these cross sections are calculated to increase because the loading on Section 3026 is projected to increase from a pre-project level of 167 mega-volt-amperes (MVA) to a post-project level of 880 MVA. The maximum post-project AC magnetic-field level on the ROW is calculated to be 406 mG in XS-24, with field levels of greater than 400 mG on the ROW calculated for all cross sections along the route of Sections 62

[10] This maximum calculated value on the ROW occurs in XS-10, XS-14, and XS-15. The maximum calculated post-project AC electric-field level at ROW edge occurs in XS-8, Calculated AC electric-field levels for XS-8 are summarized here in Table 5, while calculated AC electric-field levels for XS-10 (and all other cross-sections) are summarized in Table A-8 of Appendix A.

and 64 where the existing Section 3026 is supported on an H-frame structure (XS-16, XS-17, XS-20, XS-21, and XS-23 through XS-28). The maximum calculated post-project value at the ROW edge along the route of Section 3006 is 3.2 mG, and along the route of Section 3027 it is 12 mG.

Table 6. Summary of calculated AC magnetic-field levels (mG) for selected cross sections for average loading

Project Segment	XS	Configuration	100 feet beyond −ROW edge	−ROW edge	Max on ROW	+ROW edge	100 feet beyond +ROW edge
Route of Section 3006 (XS-2 to XS-7)	**7**	Existing	0.9	4.0	30	0.5	0.3
		Proposed	0.7	3.2	23	0.4	0.2
Route of Section 3027 (XS-8 to XS-15)	**12**	Existing	3.4	16	107	6.1	1.1
		Proposed	2.1	12	94	12	1.9
Route of Sections 62, 64 (XS-16 to XS-28)	**17**	Existing	0.2	1.0	78	11	2.1
		Proposed	2.4	3.8	405	59	12

Comparison to Environmental Assessment Criteria

Table 7 below provides a summary of the electrical phenomena associated with the operation the project's DC and AC transmission lines for comparison to environmental assessment criteria. The upper rows of the table summarize the DC electrical parameters (static electric field, static magnetic field, and ion density) for the project segment containing a DC line (route of Section 3006). The lower rows of the table summarize the AC electrical effects (AC electric field and AC magnetic field) for each project segment (route of Section 3006, route of Section 3027, and route of Sections 62 and 64). For each electrical effect and project segment, the calculated maximum[11] on the ROW and the calculated maximum at the ROW edge is provided for both existing (pre-project) and proposed (post-project) configurations. Since there are no existing DC lines, there are no pre-project levels for the DC electrical effects. Environmental assessment criteria are summarized in the final column of the table.

DC Line Fields and Space Charge

The magnitude of the **static electric field** at the ROW edges is calculated to be 6.6 kV/m or less in foul weather, and less than that in fair weather. This is well below the assessment criteria of 25 kV/m. The maximum on the ROW for either fair or foul weather (23 kV/m) also remains below this limit.

The **static magnetic field** generated by the DC line is calculated to be 0.047 G (47 mG) or less at the ROW edge, and 0.359 G (359 mG) or less on the ROW. When combined with the background geomagnetic field, the highest total static magnetic-field level on the ROW is 0.883 G (883 mG). These levels are all several thousand times below the assessment criteria.

The magnitude of the **ion density** is calculated to be less than 20,000 ions/cm^3 at the ROW edge, and 152,000 ions/cm^3 or less on the ROW for either fair or foul weather. These calculated

[11] For static electric field and ion density, which can be either negative or positive, the provided maximum values represent the maximum absolute value.

ion densities are within the range of other existing sources. Neither the federal government nor the state of Maine has standards or guidelines for ion density associated with transmission lines.

AC Line Electric and Magnetic Fields

The **AC electric field** is calculated to be 1.2 kV/m or less at the ROW edge, which is slightly less than existing levels and also is well below the assessment criteria of 4.2 kV/m (ICNIRP, 2010) and 5.0 kV/m (ICES, 2002) for exposure of the general public. The maximum calculated level on the ROW is 8.7 kV/m, which remains below the guideline of 10 kV/m specified by ICES (2002) for AC electric-field levels on a transmission line ROW and the ICNIRP and ICES Basic Restrictions.

The **AC magnetic field** for average loading is calculated to be 59 mG or less at the ROW edge, and 406 mG or less on the ROW. These post-project AC magnetic-field levels are higher than pre-project levels due to the increased loading on Section 3026 along the route of Sections 62 and 64, but they remain several times lower than the assessment criteria.

Table 7. Summary of calculated electrical parameters of the DC and AC lines compared to environmental assessment criteria

		Pre-Project		Post-Project		
	Proposed Project Segment	**±Max on ROW**	**±Max at ROW Edge**	**±Max on ROW**	**±Max at ROW Edge**	**Assessment Criteria**
Static Electric Field in Fair Weather (kV/m)	**Route of Section 3006 (XS-1 to XS-7)**	–	–	17	-2.8	25 kV/m (NRPB, 2004)
Static Electric Field in Foul Weather (kV/m)	**Route of Section 3006 (XS-1 to XS-7)**	–	–	-23	-6.6	
Static Magnetic Field (G)	**Route of Section 3006 (XS-1 to XS-7)**	–	–	0.359	0.047	4,000 G (ICNIRP, 2009) 40,000 G (infants) 80,000 G (adults) (FDA, 2014)
Ion Density in Fair Weather (ions/cm^3)	**Route of Section 3006 (XS-1 to XS-7)**	–	–	124,000	-13,600	–
Ion Density in Foul Weather (ions/cm^3)	**Route of Section 3006 (XS-1 to XS-7)**	–	–	152,000	-19,400	
AC Electric Field (kV/m)	**Route of Section 3006 (XS-2 to XS-7)**	1.6	0.3	1.6	0.3	4.2 kV/m (ICNIRP, 2010) 5.0 kV/m 10 kV/m (on ROW) (ICES, 2002)
	Route of Section 3027 (XS-8 to XS-15)	8.1	1.3	8.7	1.2	
	Route of Sections 62, 64 (XS-16 to XS-28)	7.6	1.1	7.5	1.1	
AC Magnetic Field for Average Load (mG)	**Route of Section 3006 (XS-2 to XS-7)**	64	4.0	98	3.2	2,000 mG (ICNIRP, 2010) 9,040 mG (ICES, 2002)
	Route of Section 3027 (XS-8 to XS-15)	107	16	99	12	
	Route of Sections 62, 64 (XS-16 to XS-28)	80	11	406	59	

Conclusion

This report has summarized calculations of the DC and AC electrical environment associated with existing and proposed transmission lines along the route of the proposed NECEC project. Calculations have been made using methods that have been found to match well with measurements, are accepted within the scientific and engineering community, and have been compared to applicable standards or guidelines. These calculated values were found to be below recommended limits for assessing potential effects on the environment and public health.

The DC line will produce static electric and magnetic fields and ion densities similar to those encountered in the natural environment, with magnetic-field levels similar to the Earth's static geomagnetic field and electric-field levels similar to those produced by atmospheric phenomena, weather, and friction charging. The calculated static electric-field levels everywhere on the route are below the levels recognized by the NRPB to induce annoying sensations (NRPB, 2004) and the static magnetic-field levels are likewise well below ICNIRP and FDA guidelines (FDA, 2014; ICNIRP, 2009) for static magnetic-field exposure.

The AC lines will produce levels of 60-Hertz AC electric and magnetic fields that are calculated to be below assessment criteria established by ICNIRP and the ICES, which provide guidelines on public exposure and AC electric-field levels on transmission line ROWs (ICES, 2002; ICNIRP, 2010).

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Appendix A

Summary Tables:

Static Magnetic Field
Static Electric Field
Ion Density

AC Magnetic Field
AC Electric Field

Table A-1. Calculated post-project static magnetic-field levels (mG)

XS	100 ft beyond −ROW edge	−ROW edge	Max on ROW	+ROW edge	100 ft beyond +ROW edge
1	2.8	5.7	359	47	9.4
2	4.6	13	359	13	4.6
3	2.8	5.7	359	3.8	2.1
4	2.8	5.7	359	9.4	3.8
5	2.0	3.6	359	12	4.5
6	2.8	5.7	359	9.4	3.8
7	2.8	5.7	359	9.4	3.8

Table A-2. Calculated post-project static electric-field levels (kV/m) for fair weather

XS	100 ft beyond −ROW edge	−ROW edge	Min on ROW	Max on ROW	+ROW edge	100 ft beyond +ROW edge
1	0.3	0.6	-13	17	-2.8	-0.6
2	0.4	0.7	-12	17	-0.7	-0.3
3	0.2	0.4	-12	17	-0.2	-0.1
4	0.2	0.4	-12	17	-0.5	-0.2
5	0.1	0.2	-12	17	-0.4	-0.2
6	0.2	0.2	-12	17	-0.5	-0.2
7	0.2	0.3	-12	17	-0.5	-0.2

Table A-3. Calculated post-project static electric-field levels (kV/m) for foul weather

XS	100 ft beyond −ROW edge	−ROW edge	Min on ROW	Max on ROW	+ROW edge	100 ft beyond +ROW edge
1	0.5	1.0	-23	23	-6.6	-1.6
2	0.6	1.1	-23	23	-2.0	-0.8
3	0.4	0.7	-23	23	-0.7	-0.3
4	0.4	0.7	-23	23	-1.5	-0.7
5	0.2	0.4	-23	23	-1.0	-0.6
6	0.3	0.4	-23	23	-1.5	-0.7
7	0.3	0.5	-23	23	-1.5	-0.7

Table A-4. Calculated post-project ion densities (ions/cm^3) for fair weather

XS	100 ft beyond −ROW edge	−ROW edge	±Max on ROW	+ROW edge	100 ft beyond +ROW edge
1	400	1,100	124,000	-13,600	-2,000
2	710	1,800	124,000	-2,700	-700
3	360	870	124,000	-530	-210
4	360	880	124,000	-1,800	-530
5	180	360	123,000	-1,400	-520
6	300	510	124,000	-1,800	-530
7	330	610	123,000	-1,800	-520

Table A-5. Calculated post-project ion densities (ions/cm^3) for foul weather

XS	100 ft beyond −ROW edge	−ROW edge	±Max on ROW	+ROW edge	100 ft beyond +ROW edge
1	410	1,200	151,000	-19,400	-2,300
2	720	1,900	152,000	-3,300	-800
3	370	900	152,000	-600	-230
4	370	900	152,000	-2,200	-600
5	180	360	150,000	-1,700	-580
6	300	520	152,000	-2,200	-600
7	340	630	151,000	-2,200	-600

Table A-6. Calculated AC magnetic-field levels (mG) for average loading

XS	Configuration	100 ft beyond −ROW edge	−ROW edge	Max on ROW	+ROW edge	100 ft beyond +ROW edge
2	Existing	0.6	3.0	28	0.3	0.2
	Proposed	0.6	3.1	29	0.4	0.2
3	Existing	0.6	1.8	64	0.3	0.2
	Proposed	1.0	2.7	98	0.5	0.3
4	Existing	0.5	1.2	45	0.5	0.2
	Proposed	0.4	1.0	36	0.4	0.2
5	Existing	0.4	1.4	45	3.0	0.5
	Proposed	0.4	1.3	35	3.2	0.5
6	Existing	0.6	3.7	32	0.3	0.2
	Proposed	0.5	3.2	22	0.2	0.1
7	Existing	0.9	4.0	30	0.5	0.3
	Proposed	0.7	3.2	23	0.4	0.2
8	Existing	0.3	0.6	68	4.3	1.2
	Proposed	0.4	0.8	55	4.4	1.2
9	Existing	0.3	0.6	68	2.3	0.8
	Proposed	0.4	0.7	55	2.3	0.9
10	Existing	3.4	16	107	3.4	1.4
	Proposed	1.6	11	99	11	1.7
11	Existing	3.4	16	107	6.2	1.1
	Proposed	2.1	12	94	12	1.9
12	Existing	3.4	16	107	6.1	1.1
	Proposed	2.1	12	94	12	1.9
13	Existing	3.4	16	107	6.0	1.1
	Proposed	2.0	12	95	11	1.8
14	Existing	3.3	16	107	3.5	0.9
	Proposed	1.7	11	97	6.6	1.1
15	Existing	3.4	16	107	0.8	0.4
	Proposed	1.6	11	99	1.3	0.5
16	Existing	0.9	5.3	75	4.9	1.6
	Proposed	2.2	4.4	404	25	7.9
17	Existing	0.2	1.0	78	11	2.1
	Proposed	2.4	3.8	405	59	12
18	Existing	1.2	4.7	48	5.9	1.9
	Proposed	4.3	11	242	30	9.3
19	Existing	0.5	3.5	78	3.5	1.1
	Proposed	2.1	3.1	406	20	6.8

XS	Configuration	100 ft beyond −ROW edge	−ROW edge	Max on ROW	+ROW edge	100 ft beyond +ROW edge
20	Existing	0.5	3.5	78	11	2.0
	Proposed	2.1	3.1	406	59	12
21	Existing	0.5	3.3	80	6.2	1.5
	Proposed	2.5	3.6	406	36	9.4
22	Existing	1.0	2.8	47	3.7	1.4
	Proposed	3.6	7.7	242	19	7.1
23	Existing	0.3	1.5	78	4.6	1.3
	Proposed	2.0	2.5	405	27	8.0
24	Existing	0.4	2.6	78	4.9	1.4
	Proposed	2.4	4.3	406	26	8.0
25	Existing	0.8	2.3	75	2.4	1.0
	Proposed	3.4	7.1	406	12	4.9
26	Existing	0.5	2.5	78	2.1	0.9
	Proposed	3.4	7.1	406	12	4.9
27	Existing	0.4	2.6	78	4.9	1.4
	Proposed	2.4	4.3	406	26	8.0
28	Existing	0.4	2.8	77	4.9	1.5
	Proposed	2.4	4.3	406	26	8.0

Table A-7. Calculated AC magnetic-field levels (mG) for peak loading

XS	Configuration	100 ft beyond −ROW edge	−ROW edge	Max on ROW	+ROW edge	100 ft beyond +ROW edge
2	Existing	2.2	12	110	1.4	0.7
	Proposed	2.1	11	104	1.3	0.6
3	Existing	1.7	4.6	169	0.9	0.5
	Proposed	1.2	3.3	121	0.6	0.4
4	Existing	1.5	4.1	148	1.5	0.8
	Proposed	1.3	3.5	128	1.3	0.7
5	Existing	1.5	3.5	197	21	4.3
	Proposed	1.2	2.8	182	20	3.9
6	Existing	3.5	21	118	1.5	0.8
	Proposed	3.3	21	127	1.4	0.8
7	Existing	4.5	20	152	2.2	1.2
	Proposed	4.6	21	156	2.3	1.2
8	Existing	1.1	2.3	217	7.3	2.4
	Proposed	0.8	1.5	97	8.0	2.1
9	Existing	1.1	2.3	216	6.8	2.3
	Proposed	0.8	1.4	99	4.0	1.6
10	Existing	11	51	338	11	4.5
	Proposed	2.9	19	172	19	3.0
11	Existing	11	51	338	9.5	2.6
	Proposed	3.7	21	162	14	2.7
12	Existing	11	50	331	9.5	2.6
	Proposed	3.8	22	162	14	2.6
13	Existing	11	50	331	10	2.9
	Proposed	3.6	21	164	14	2.5
14	Existing	10	50	332	10	2.6
	Proposed	3.0	19	171	11	1.9
15	Existing	10	50	332	1.9	1.0
	Proposed	2.8	19	172	2.2	0.8
16	Existing	3.2	13	240	16	5.4
	Proposed	4.3	10	504	32	10
17	Existing	0.4	3.0	251	35	6.7
	Proposed	2.4	2.8	507	73	15
18	Existing	3.5	13	154	19	5.8
	Proposed	5.7	16	303	37	12
19	Existing	0.9	8.0	251	11	3.6
	Proposed	1.8	4.2	507	24	8.2
20	Existing	0.9	8.0	251	35	6.6
	Proposed	1.8	4.2	507	73	15

XS	Configuration	100 ft beyond −ROW edge	−ROW edge	Max on ROW	+ROW edge	100 ft beyond +ROW edge
21	Existing	0.7	7.2	255	20	4.9
	Proposed	2.4	3.8	508	44	11
22	Existing	2.8	7.8	151	12	4.4
	Proposed	4.8	11	302	24	8.8
23	Existing	0.4	3.4	251	15	4.3
	Proposed	2.0	2.1	506	33	9.8
24	Existing	0.4	7.4	242	15	4.3
	Proposed	3.1	5.3	507	33	10
25	Existing	1.6	3.7	232	7.3	3.1
	Proposed	4.2	8.4	507	15	6.1
26	Existing	0.3	6.5	244	6.2	2.5
	Proposed	4.2	8.4	507	15	6.1
27	Existing	0.4	7.4	242	15	4.3
	Proposed	3.1	5.3	507	33	10
28	Existing	0.6	8.3	239	15	4.4
	Proposed	3.1	5.3	507	33	10

Table A-8. Calculated AC electric-field levels (kV/m)

XS	Configuration	100 ft beyond −ROW edge	−ROW edge	Max on ROW	+ROW edge	100 ft beyond +ROW edge
2	Existing	< 0.1	0.2	1.5	< 0.1	< 0.1
	Proposed	< 0.1	0.2	1.5	< 0.1	< 0.1
3	Existing	< 0.1	< 0.1	1.6	< 0.1	< 0.1
	Proposed	< 0.1	< 0.1	1.6	< 0.1	< 0.1
4	Existing	< 0.1	< 0.1	1.6	< 0.1	< 0.1
	Proposed	< 0.1	< 0.1	1.6	< 0.1	< 0.1
5	Existing	< 0.1	< 0.1	1.6	0.2	< 0.1
	Proposed	< 0.1	< 0.1	1.6	0.2	< 0.1
6	Existing	< 0.1	0.3	1.6	< 0.1	< 0.1
	Proposed	< 0.1	0.3	1.6	< 0.1	< 0.1
7	Existing	< 0.1	0.2	1.6	< 0.1	< 0.1
	Proposed	< 0.1	0.2	1.6	< 0.1	< 0.1
8	Existing	< 0.1	0.1	8.1	1.3	0.2
	Proposed	< 0.1	0.1	8.4	1.2	0.2
9	Existing	< 0.1	0.1	8.1	0.3	0.1
	Proposed	< 0.1	0.1	8.4	0.3	0.1
10	Existing	0.1	1.1	7.2	0.1	< 0.1
	Proposed	0.1	1.1	8.7	1.1	0.1
11	Existing	0.1	1.1	7.2	< 0.1	< 0.1
	Proposed	0.1	1.1	7.5	< 0.1	< 0.1
12	Existing	0.1	1.1	7.2	< 0.1	< 0.1
	Proposed	0.1	1.1	7.5	< 0.1	< 0.1
13	Existing	0.1	1.1	7.2	< 0.1	< 0.1
	Proposed	0.1	1.1	7.6	< 0.1	< 0.1
14	Existing	0.1	1.1	7.2	0.3	< 0.1
	Proposed	0.1	1.1	8.7	0.4	< 0.1
15	Existing	0.1	1.1	7.2	< 0.1	< 0.1
	Proposed	0.1	1.1	8.7	< 0.1	< 0.1
16	Existing	< 0.1	0.3	7.3	0.2	< 0.1
	Proposed	< 0.1	0.3	7.5	0.2	< 0.1
17	Existing	< 0.1	< 0.1	7.6	1.1	0.1
	Proposed	< 0.1	< 0.1	7.5	1.1	0.1
18	Existing	< 0.1	0.1	7.6	0.2	0.1
	Proposed	< 0.1	0.1	7.5	0.2	0.1
19	Existing	< 0.1	0.1	7.6	0.2	< 0.1
	Proposed	< 0.1	< 0.1	7.5	0.2	< 0.1
20	Existing	< 0.1	0.1	7.6	1.1	0.1
	Proposed	< 0.1	< 0.1	7.5	1.1	0.1

XS	Configuration	100 ft beyond −ROW edge	−ROW edge	Max on ROW	+ROW edge	100 ft beyond +ROW edge
21	Existing	< 0.1	0.1	7.6	0.6	< 0.1
	Proposed	< 0.1	< 0.1	7.5	0.6	< 0.1
22	Existing	< 0.1	< 0.1	7.6	0.2	< 0.1
	Proposed	< 0.1	< 0.1	7.5	0.2	< 0.1
23	Existing	< 0.1	< 0.1	7.6	0.4	< 0.1
	Proposed	< 0.1	< 0.1	7.5	0.4	< 0.1
24	Existing	< 0.1	0.3	7.6	0.4	< 0.1
	Proposed	< 0.1	< 0.1	7.5	0.4	< 0.1
25	Existing	< 0.1	0.2	7.4	0.1	< 0.1
	Proposed	< 0.1	0.1	7.5	0.1	< 0.1
26	Existing	< 0.1	0.3	7.6	0.1	< 0.1
	Proposed	< 0.1	0.1	7.5	0.1	< 0.1
27	Existing	< 0.1	0.3	7.6	0.4	< 0.1
	Proposed	< 0.1	< 0.1	7.5	0.4	< 0.1
28	Existing	< 0.1	0.3	7.5	0.4	< 0.1
	Proposed	< 0.1	< 0.1	7.5	0.4	< 0.1

Appendix B

Graphical Profiles of Calculated Static Electric and Magnetic Fields and Ion Densities

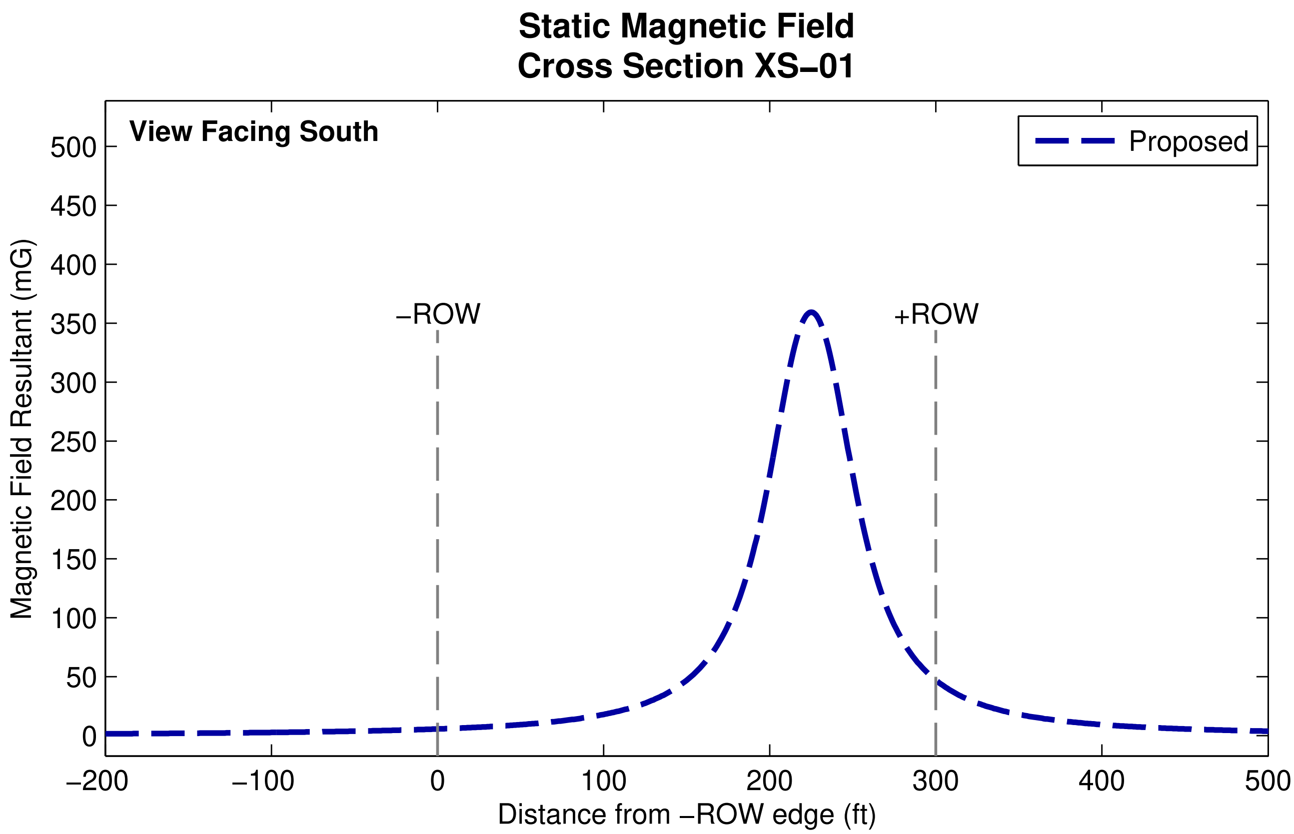

Figure B-1. Calculated post-project static magnetic-field profile along XS-01.

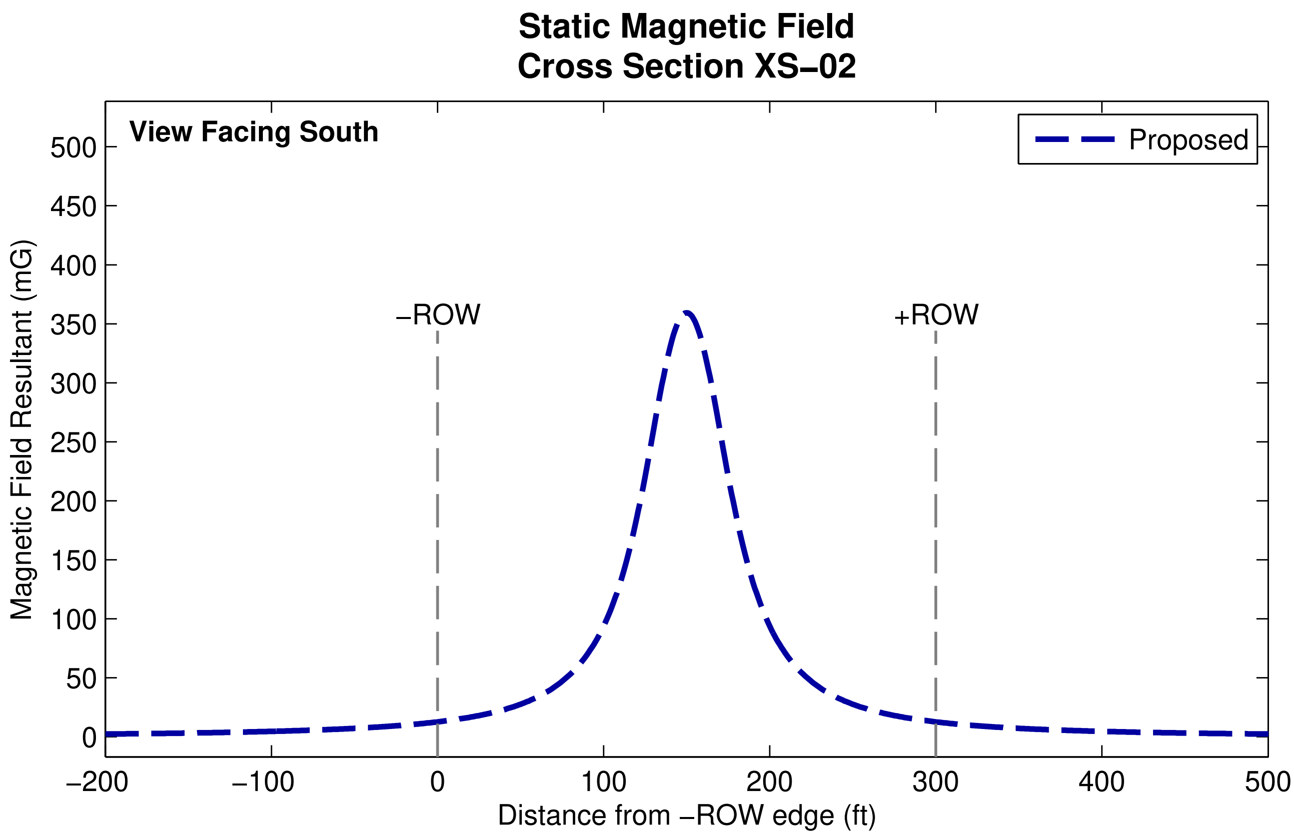

Figure B-2. Calculated post-project static magnetic-field profile along XS-02.

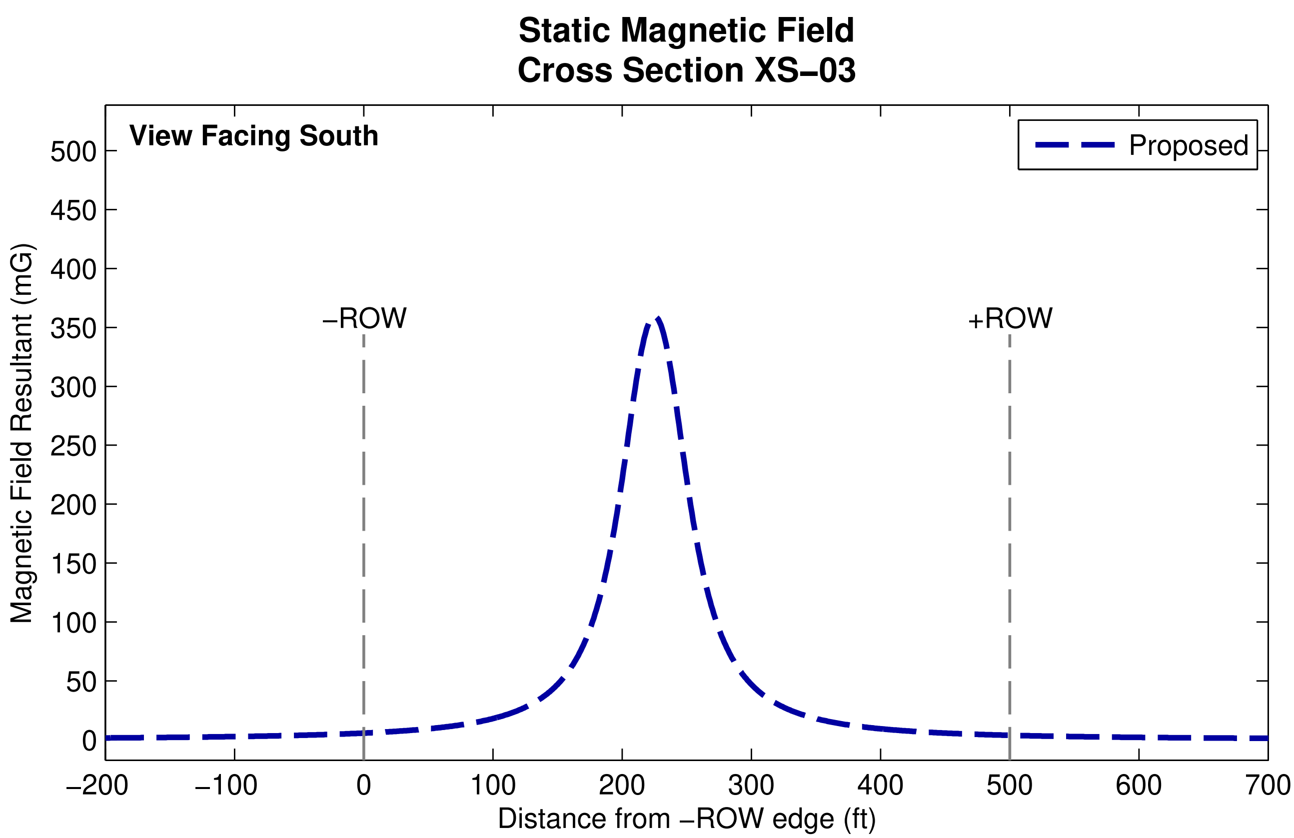

Figure B-3. Calculated post-project static magnetic-field profile along XS-03.

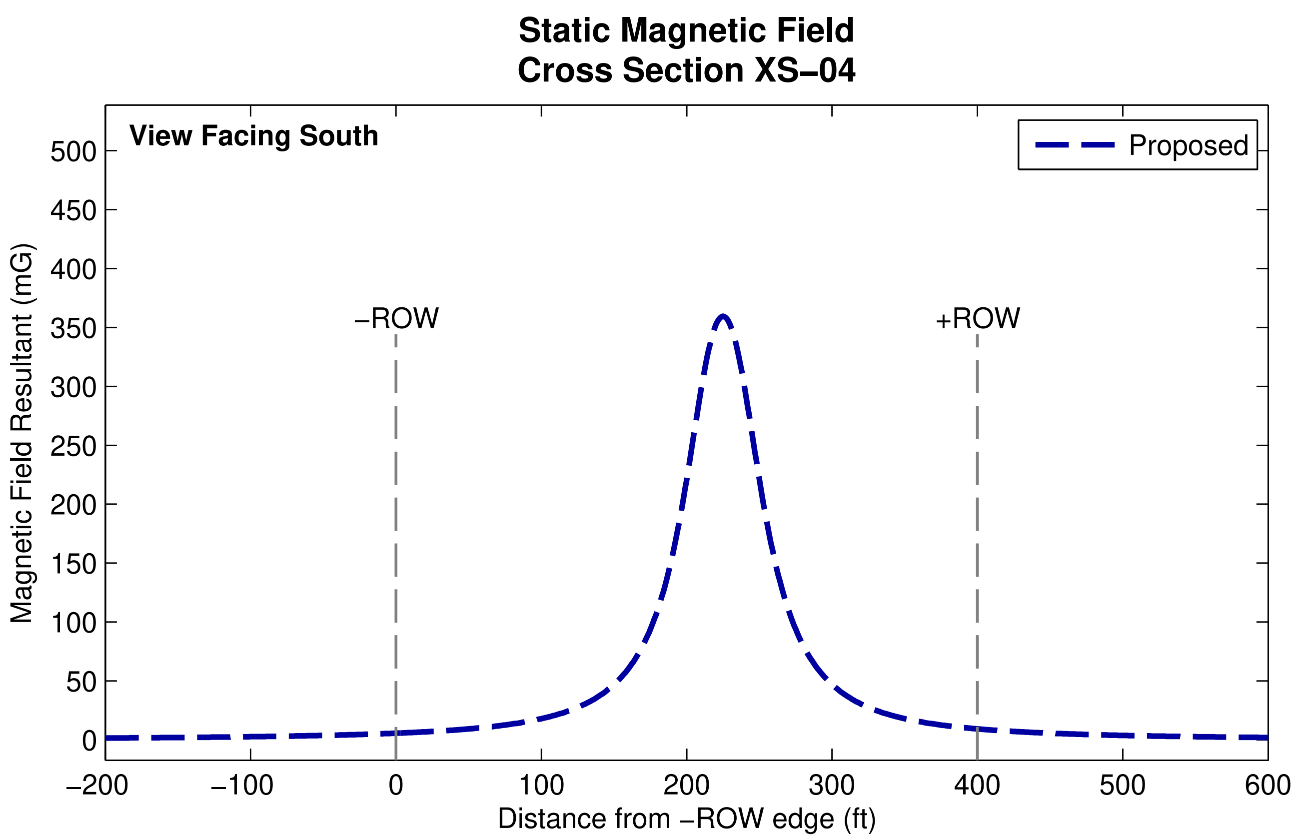

Figure B-4. Calculated post-project static magnetic-field profile along XS-04.

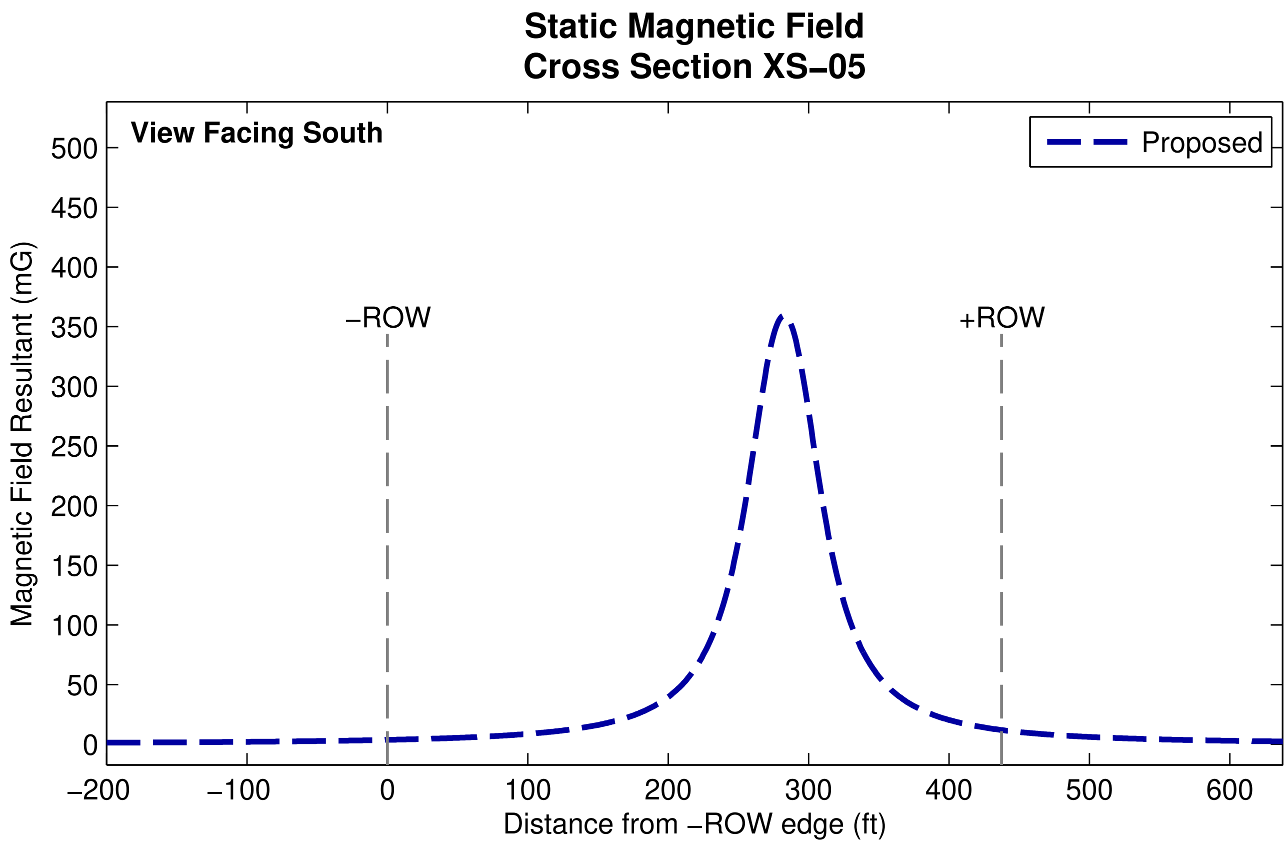

Figure B-5. Calculated post-project static magnetic-field profile along XS-05.

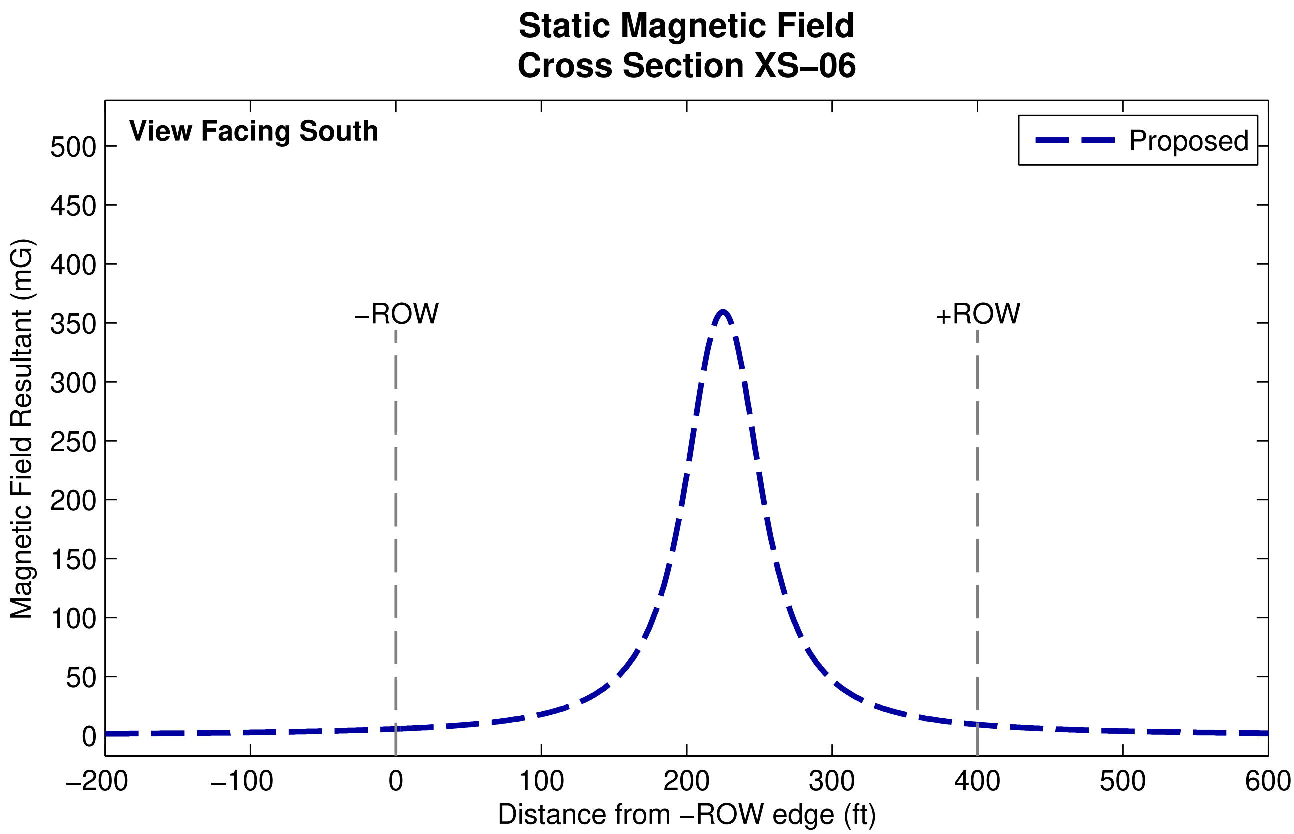

Figure B-6. Calculated post-project static magnetic-field profile along XS-06.

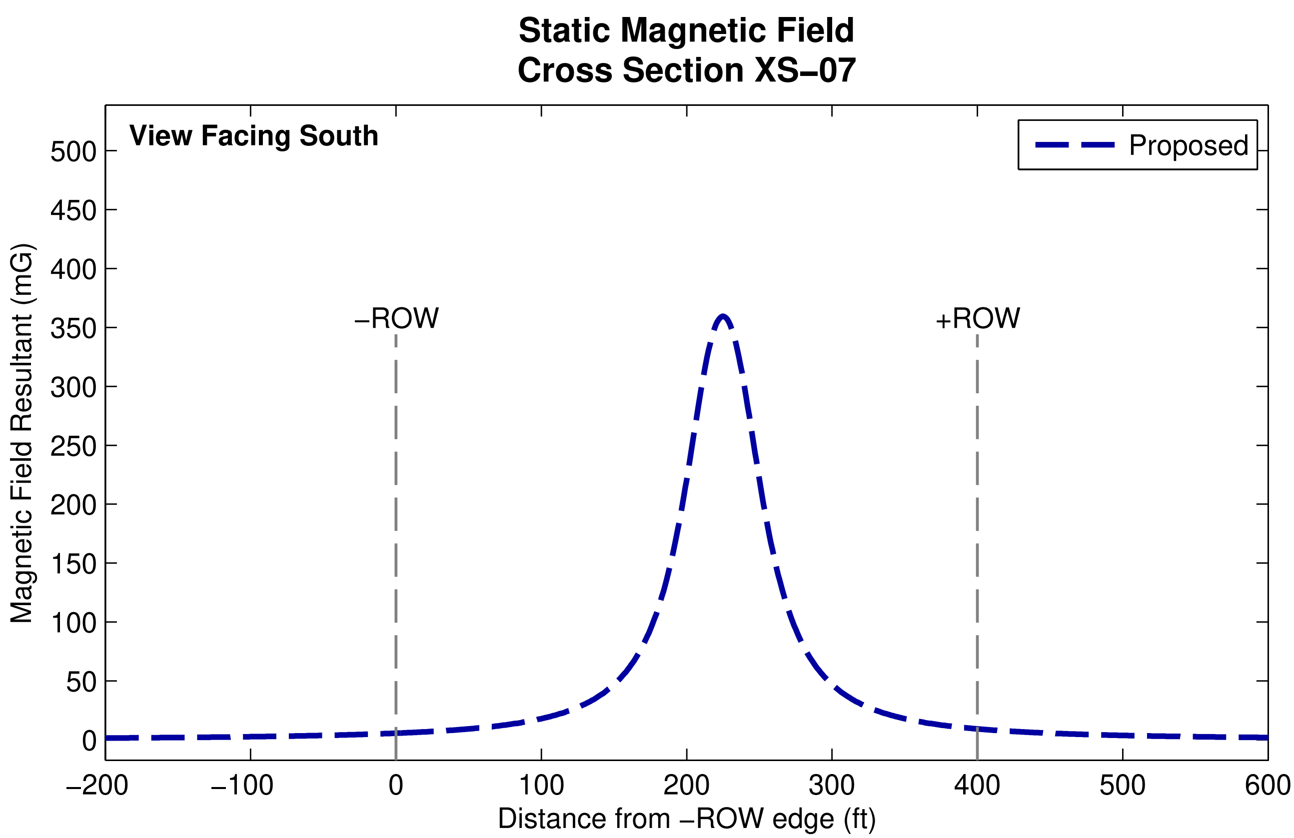

Figure B-7. Calculated post-project static magnetic-field profile along XS-07.

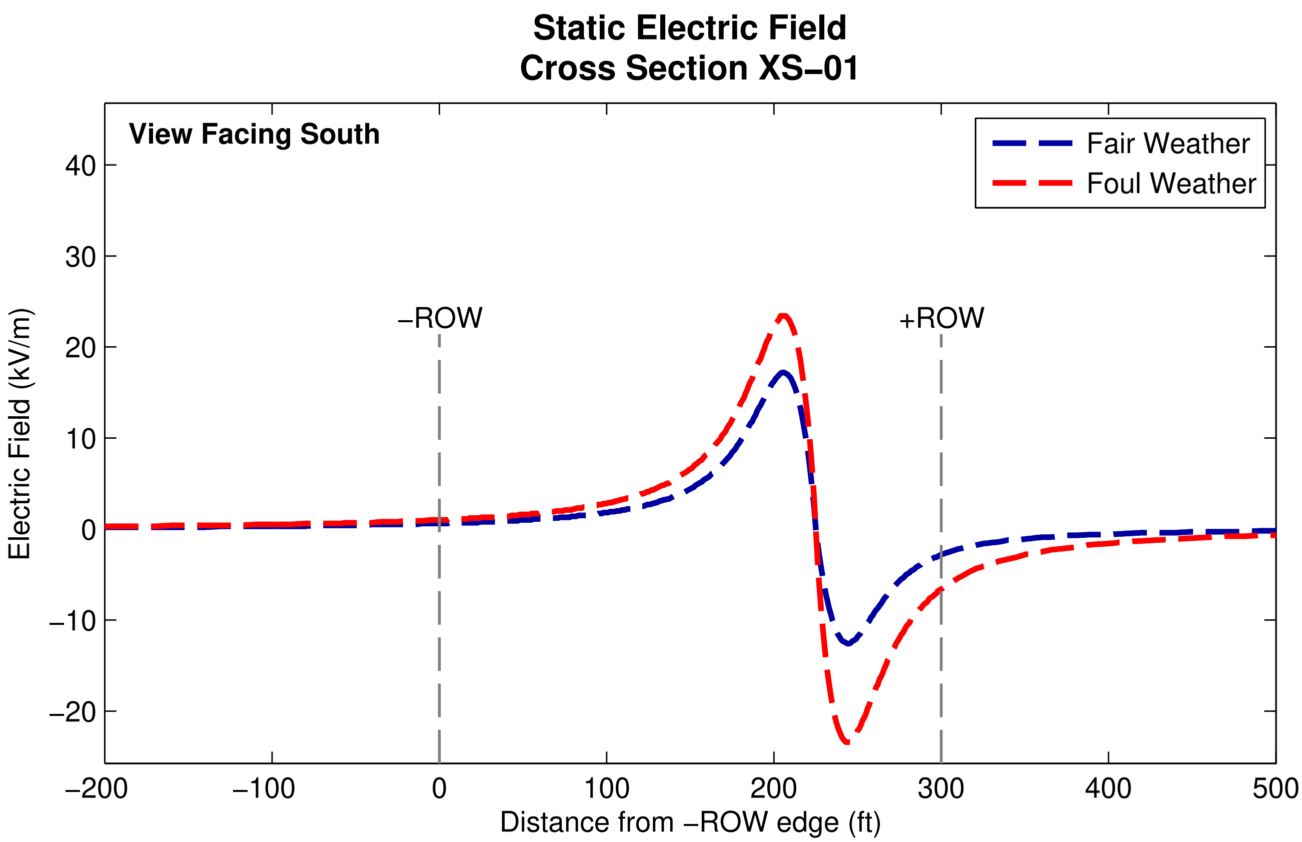

Figure B-8. Calculated post-project static electric-field profiles along XS-01.

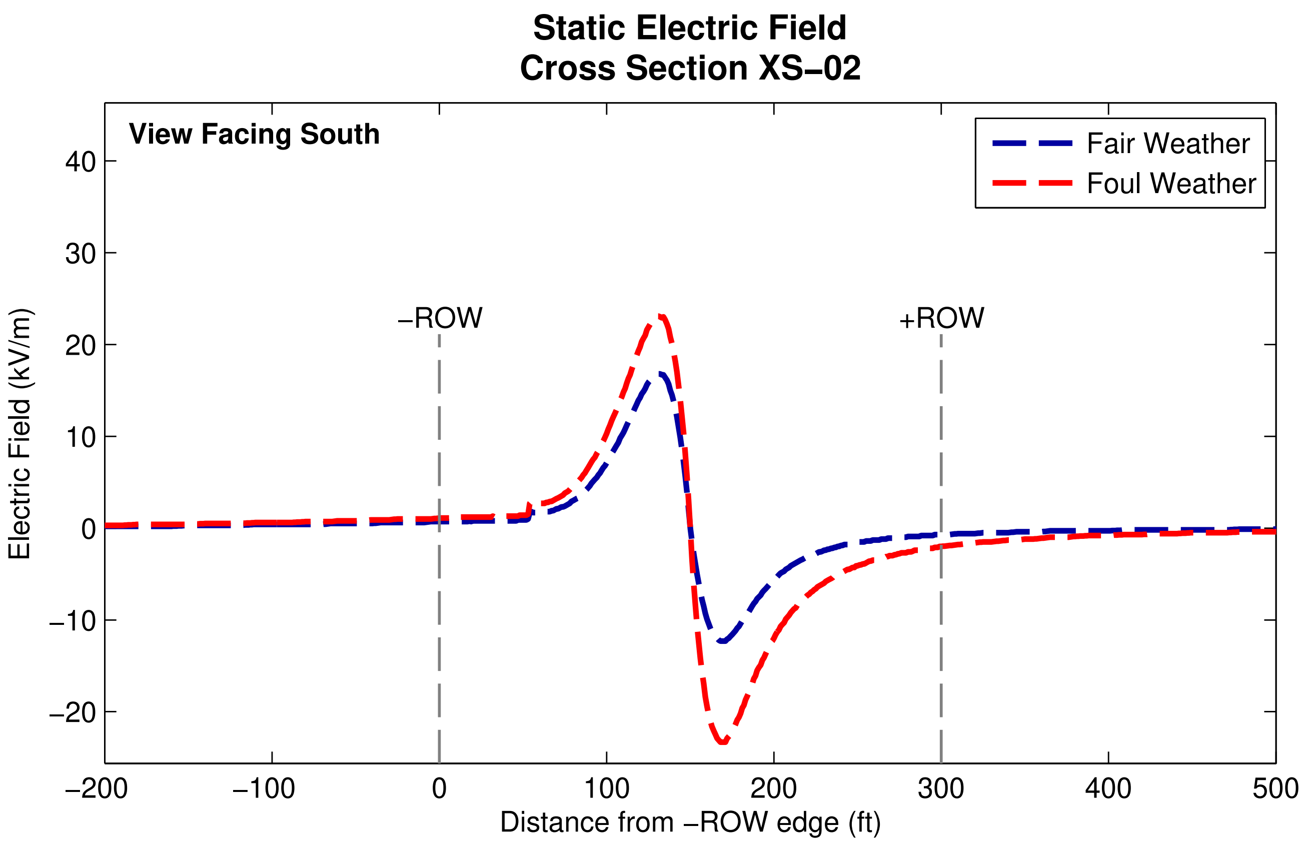

Figure B-9. Calculated post-project static electric-field profiles along XS-02.

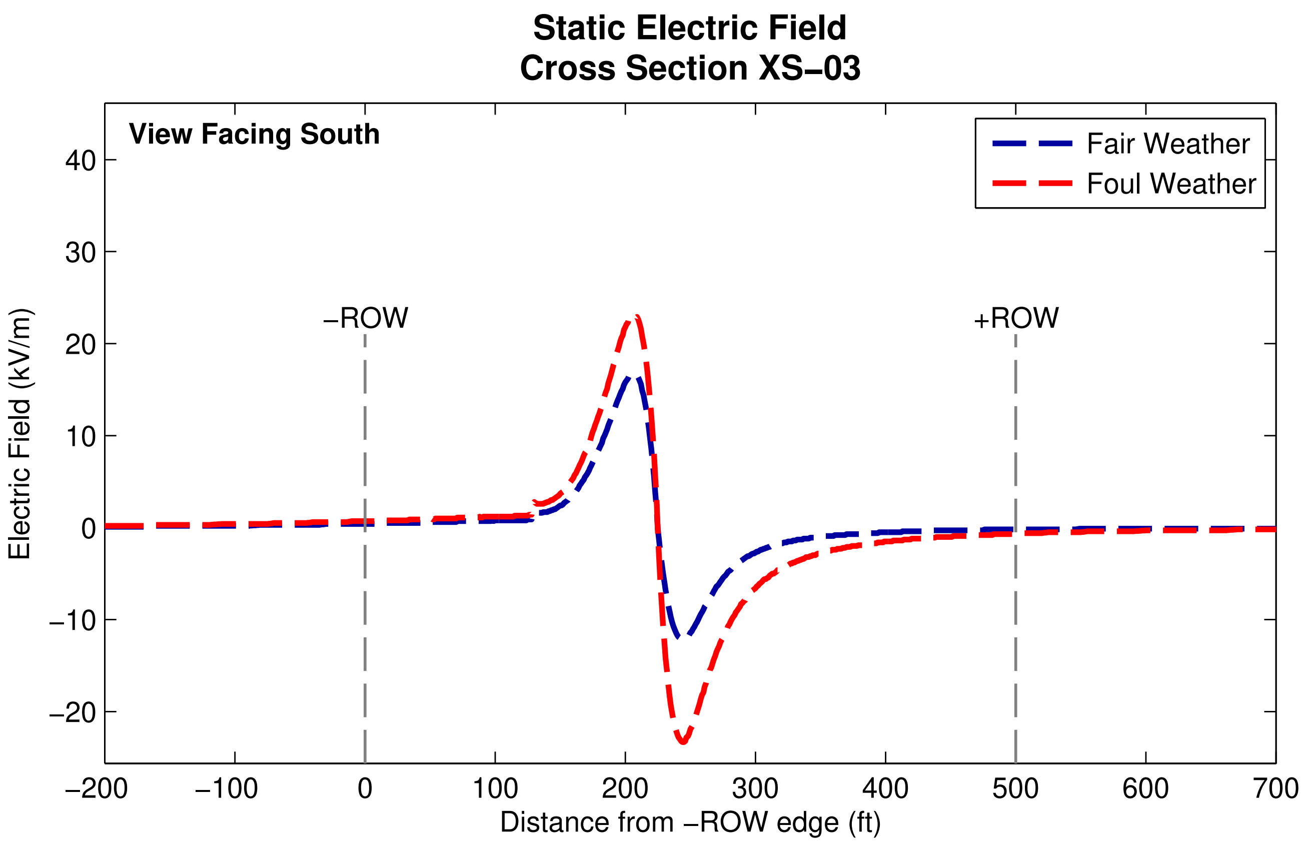

Figure B-10. Calculated post-project static electric-field profiles along XS-03.

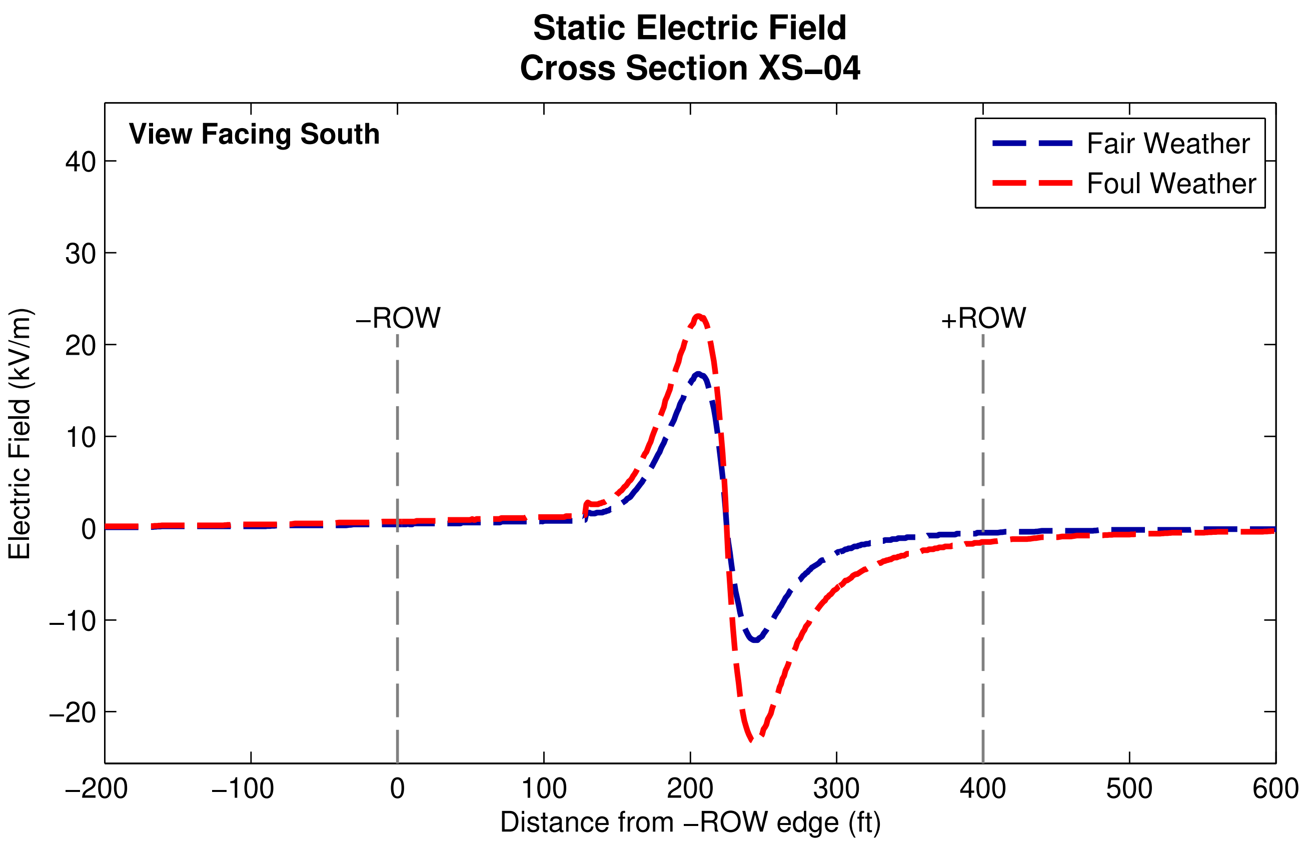

Figure B-11. Calculated post-project static electric-field profiles along XS-04.

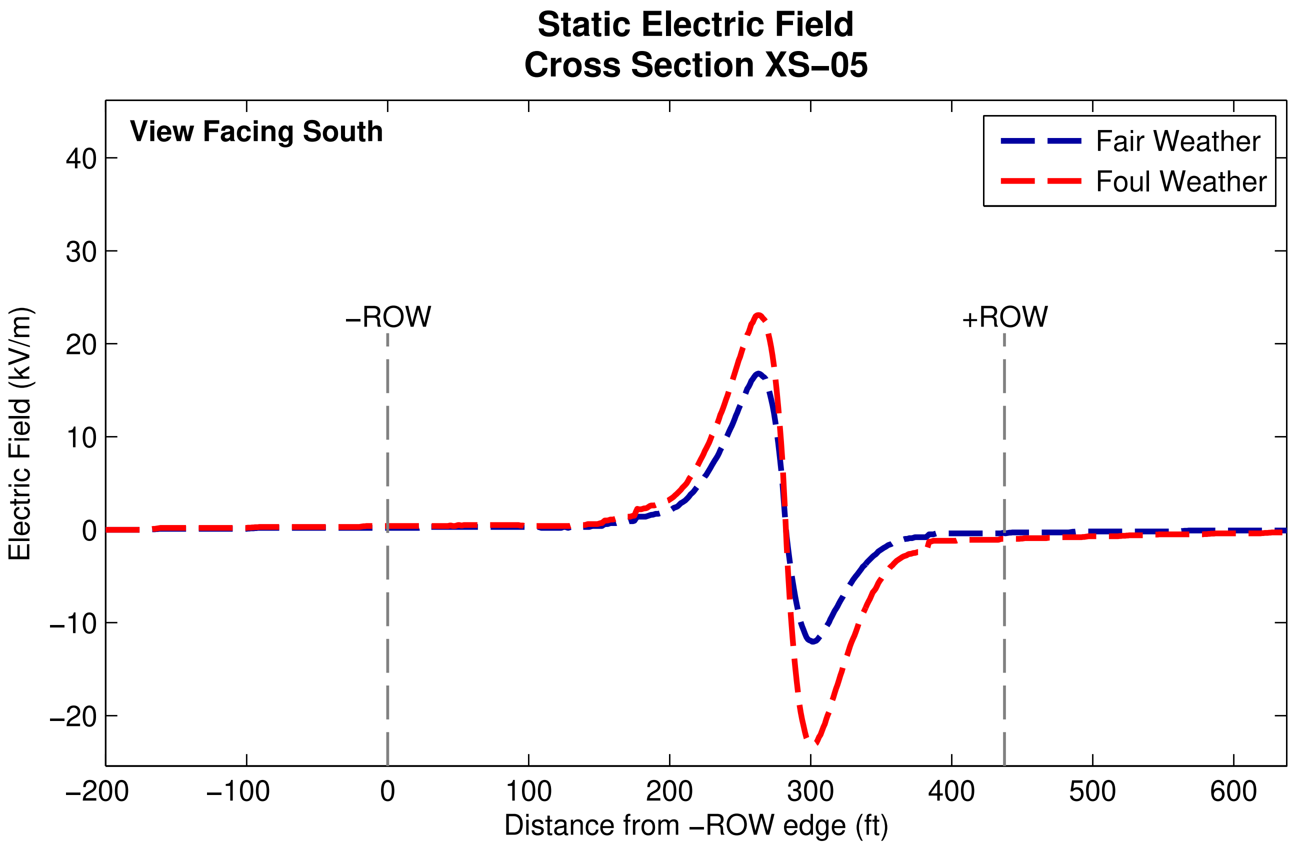

Figure B-12. Calculated post-project static electric-field profiles along XS-05.

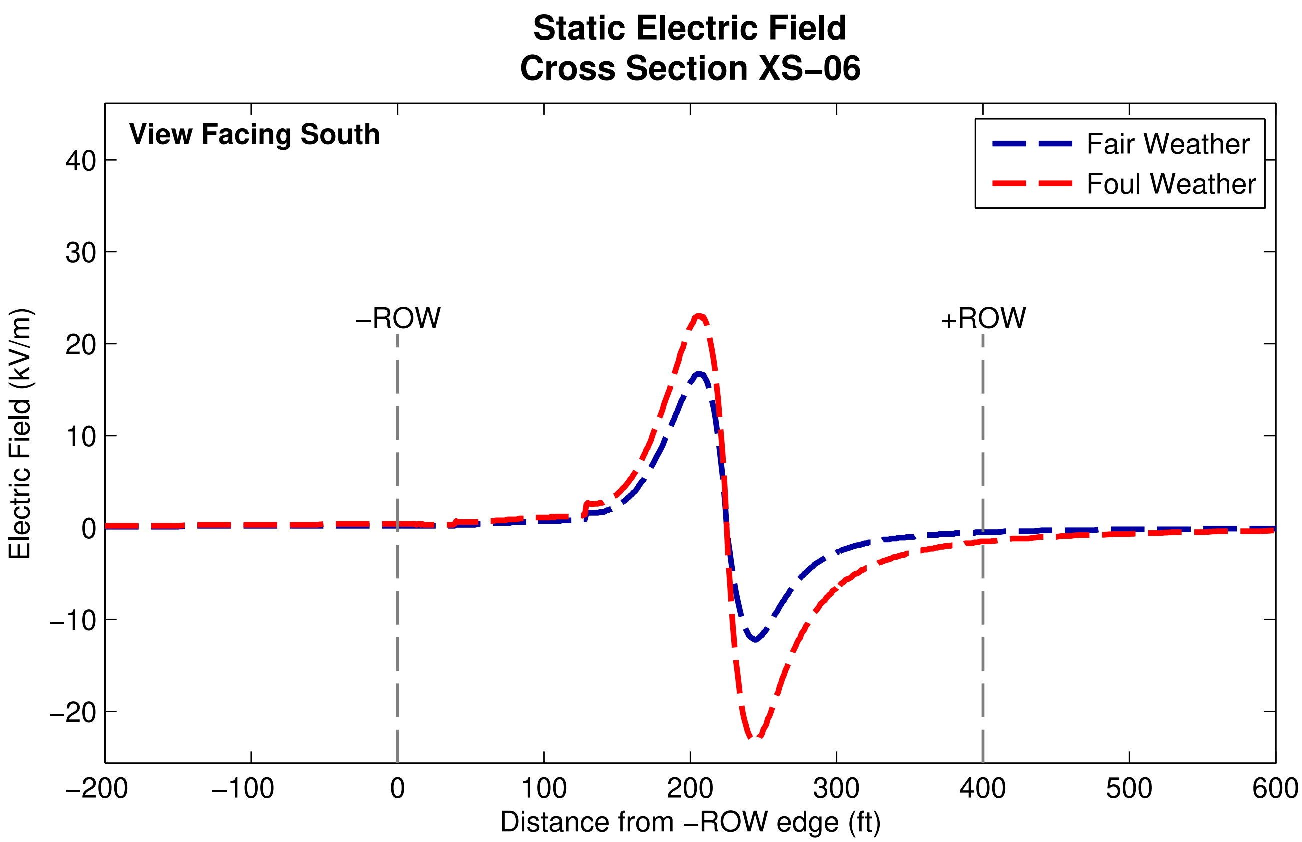

Figure B-13. Calculated post-project static electric-field profiles along XS-06.

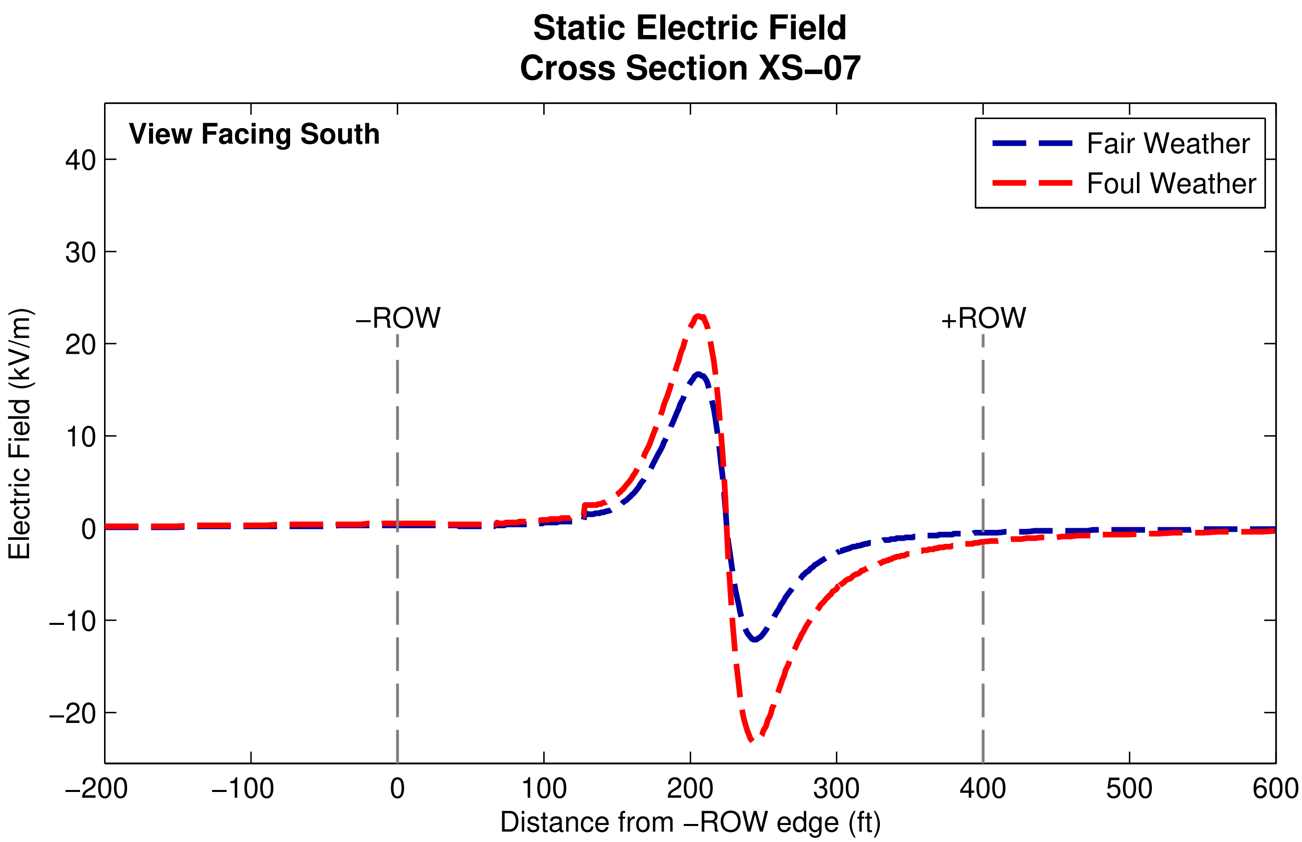

Figure B-14. Calculated post-project static electric-field profiles along XS-07.

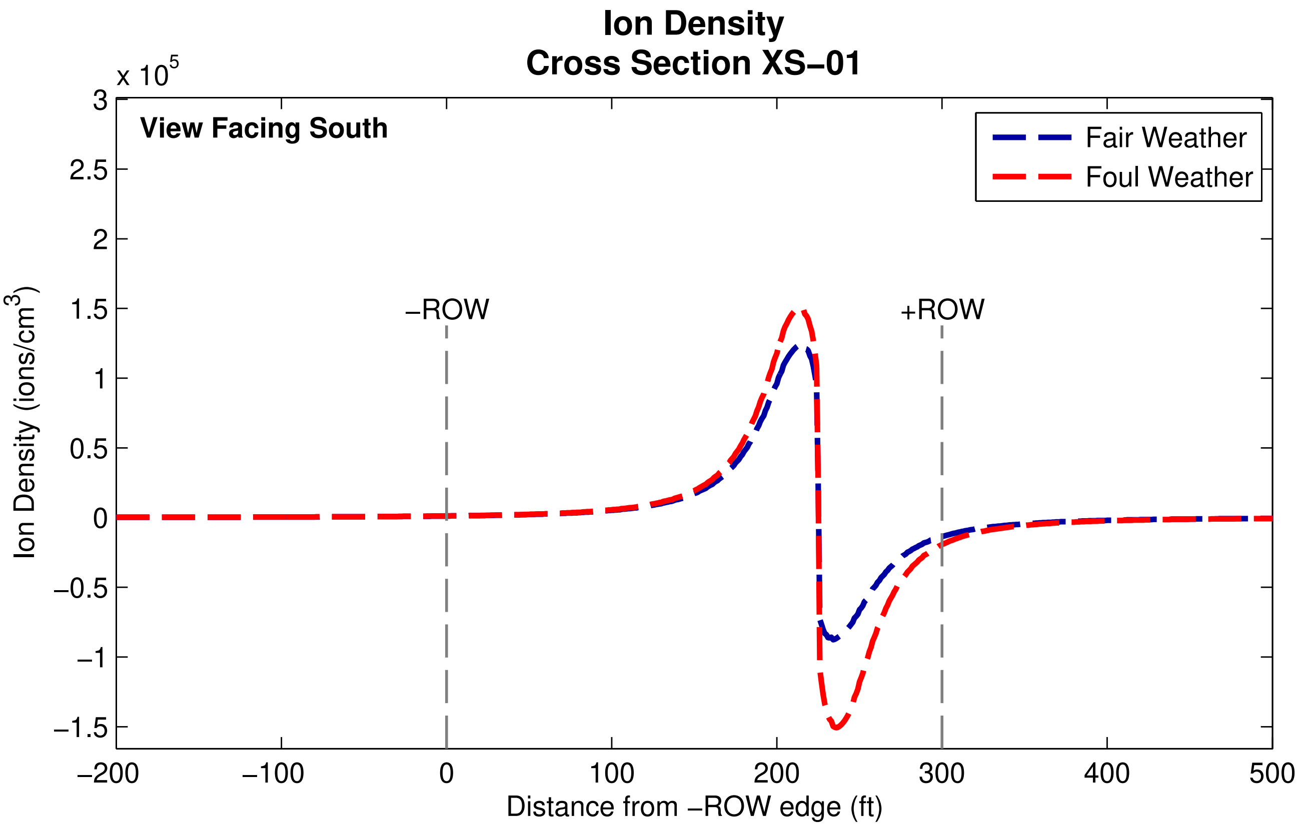

Figure B-15. Calculated post-project ion density profiles along XS-01. Negative density corresponds to density of negative ions

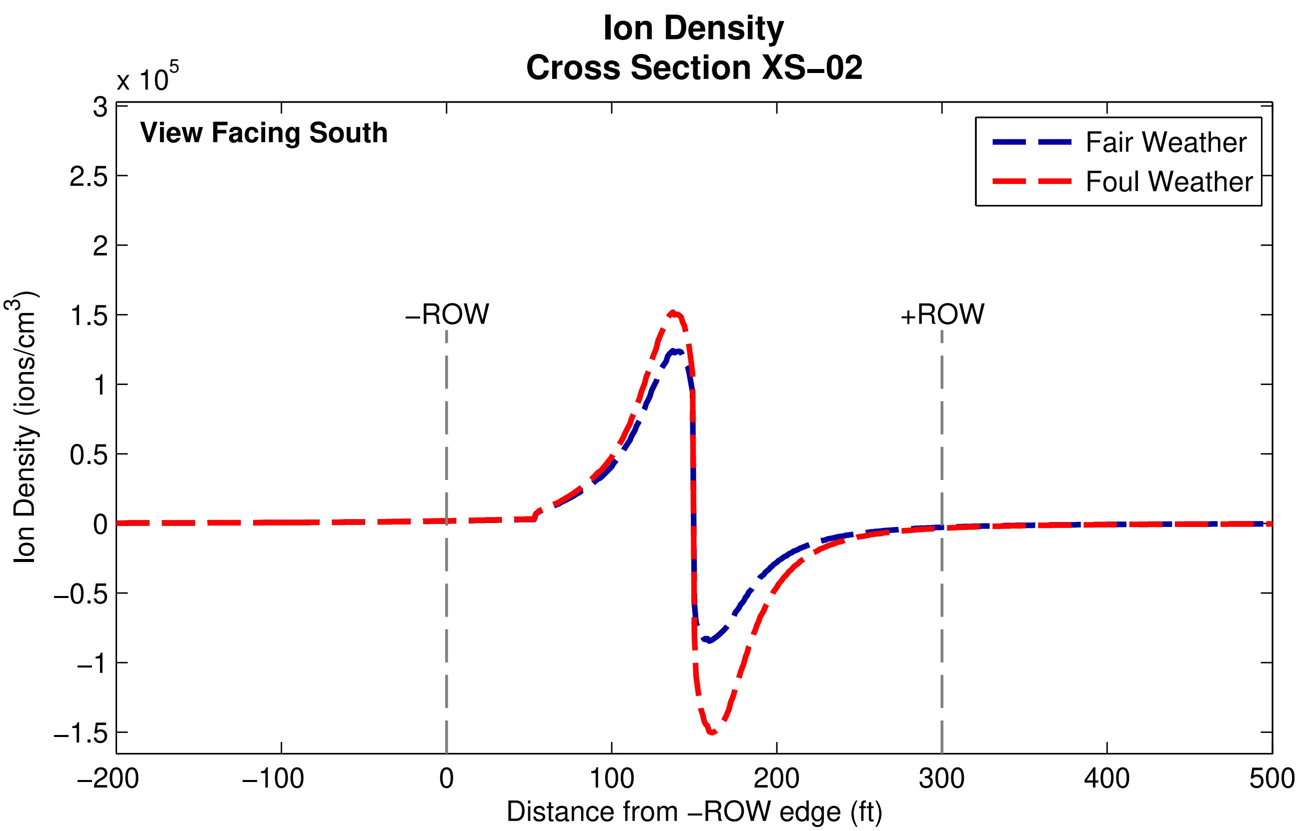

Figure B-16. Calculated post-project ion density profiles along XS-02. Negative density corresponds to density of negative ions

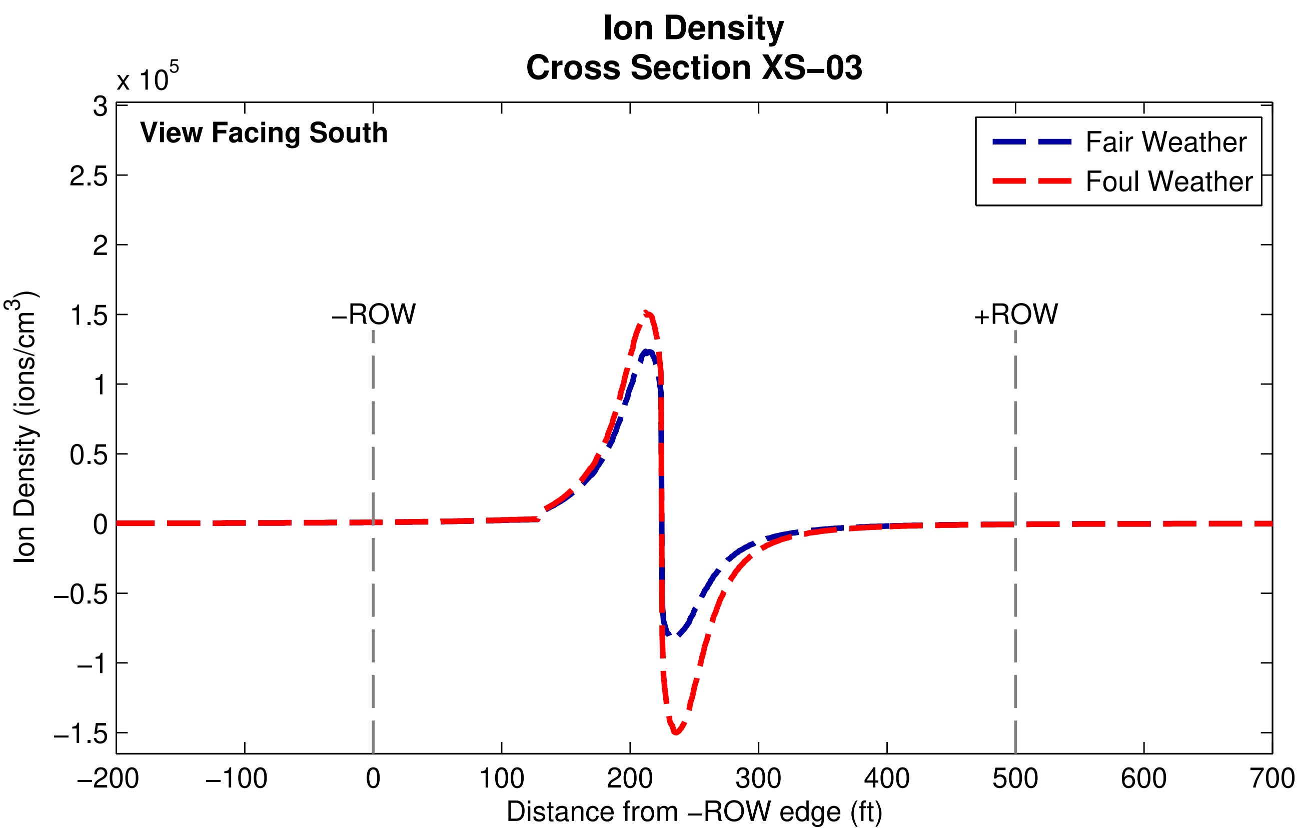

Figure B-17. Calculated post-project ion density profiles along XS-03. Negative density corresponds to density of negative ions

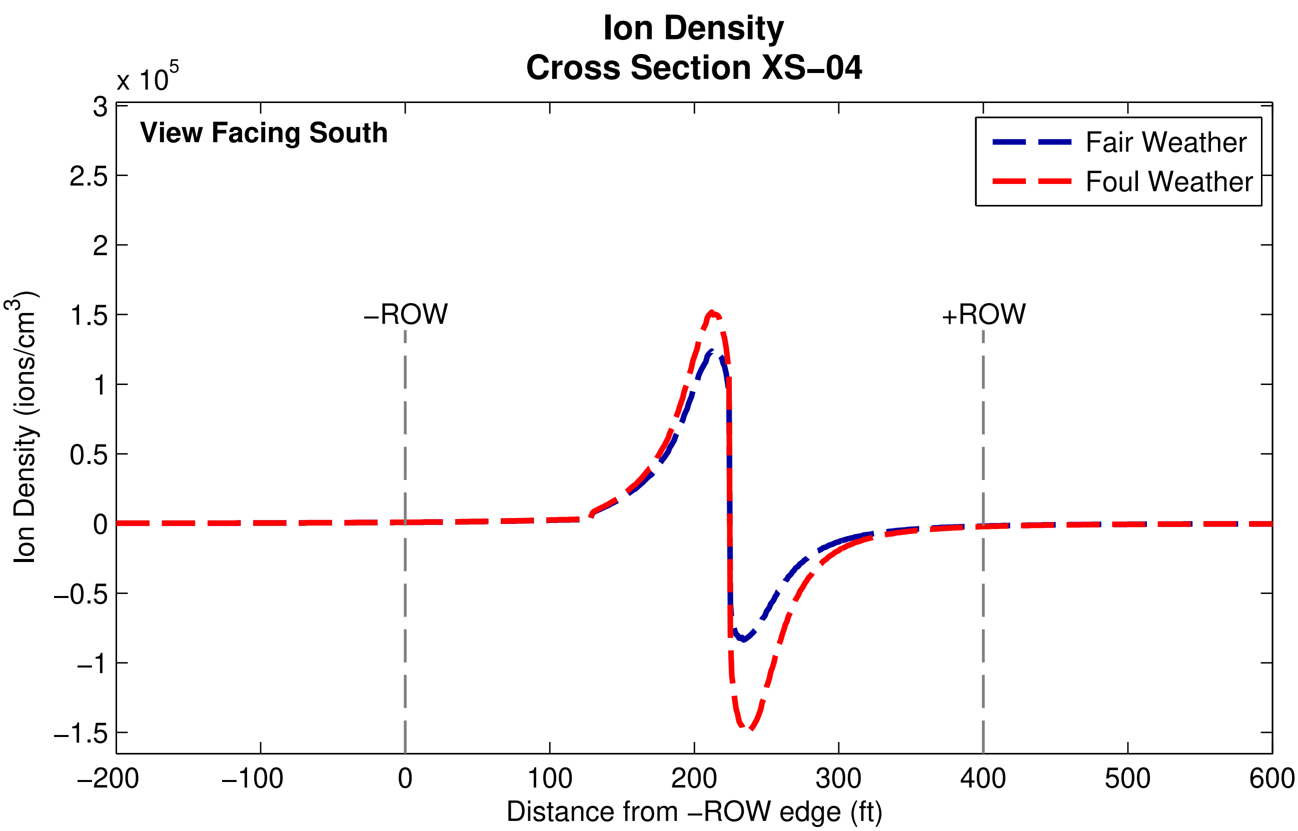

Figure B-18. Calculated post-project ion density profiles along XS-04. Negative density corresponds to density of negative ions

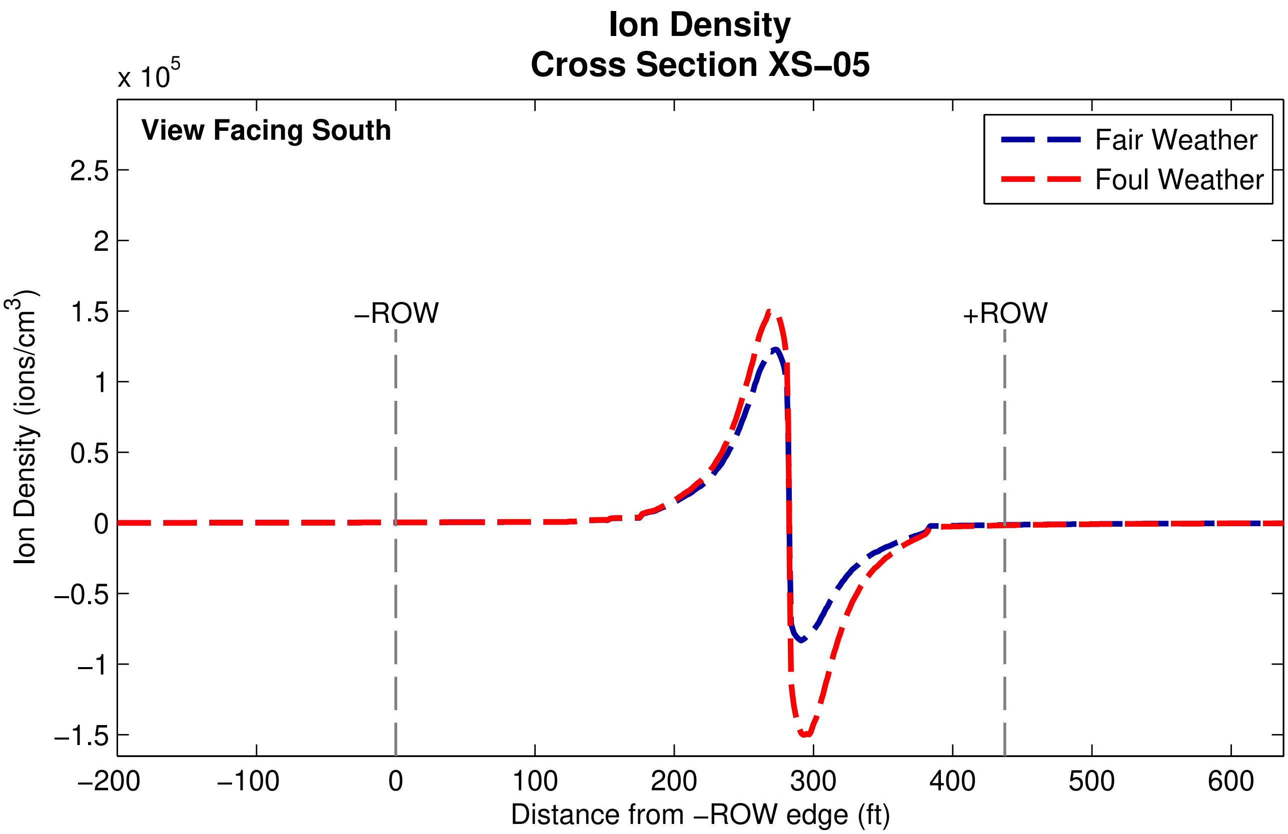

Figure B-19. Calculated post-project ion density profiles along XS-05. Negative density corresponds to density of negative ions

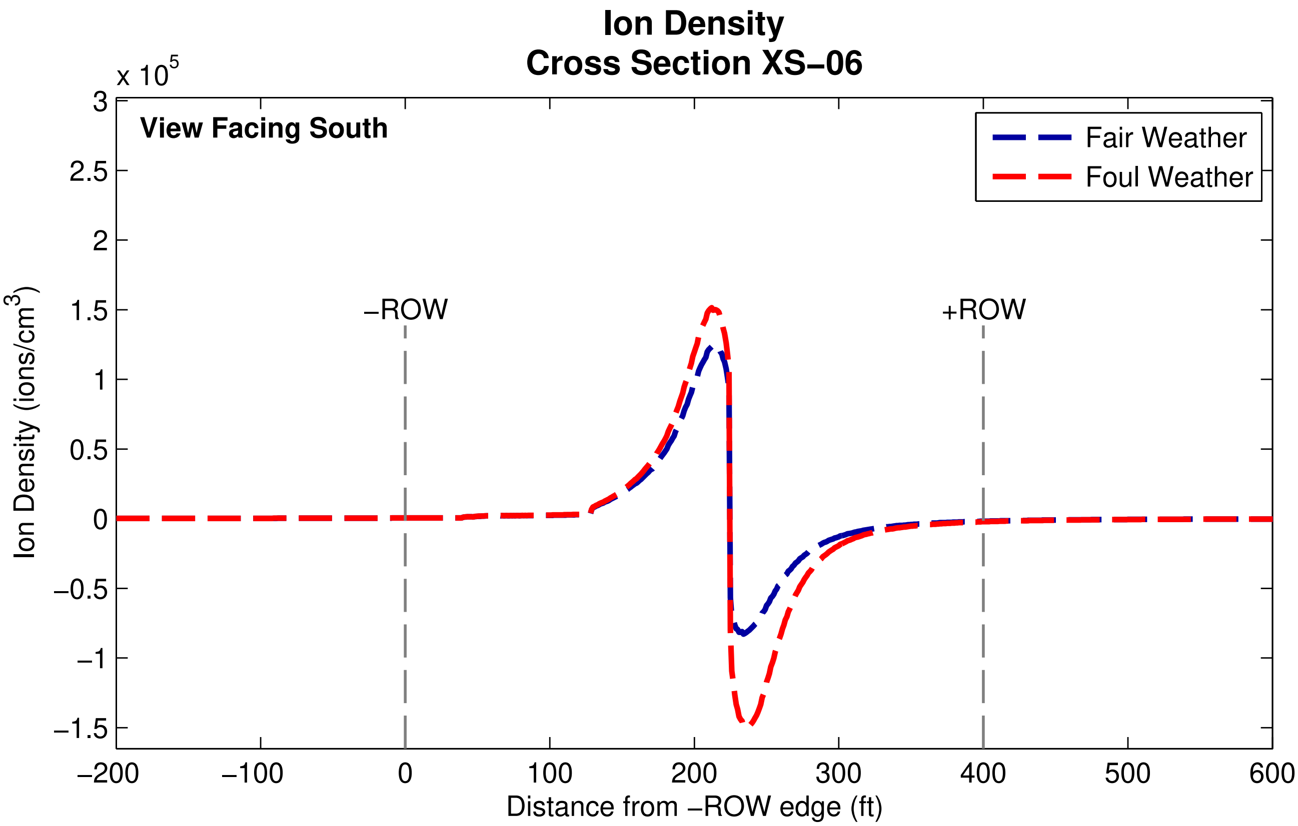

Figure B-20. Calculated post-project ion density profiles along XS-06. Negative density corresponds to density of negative ions

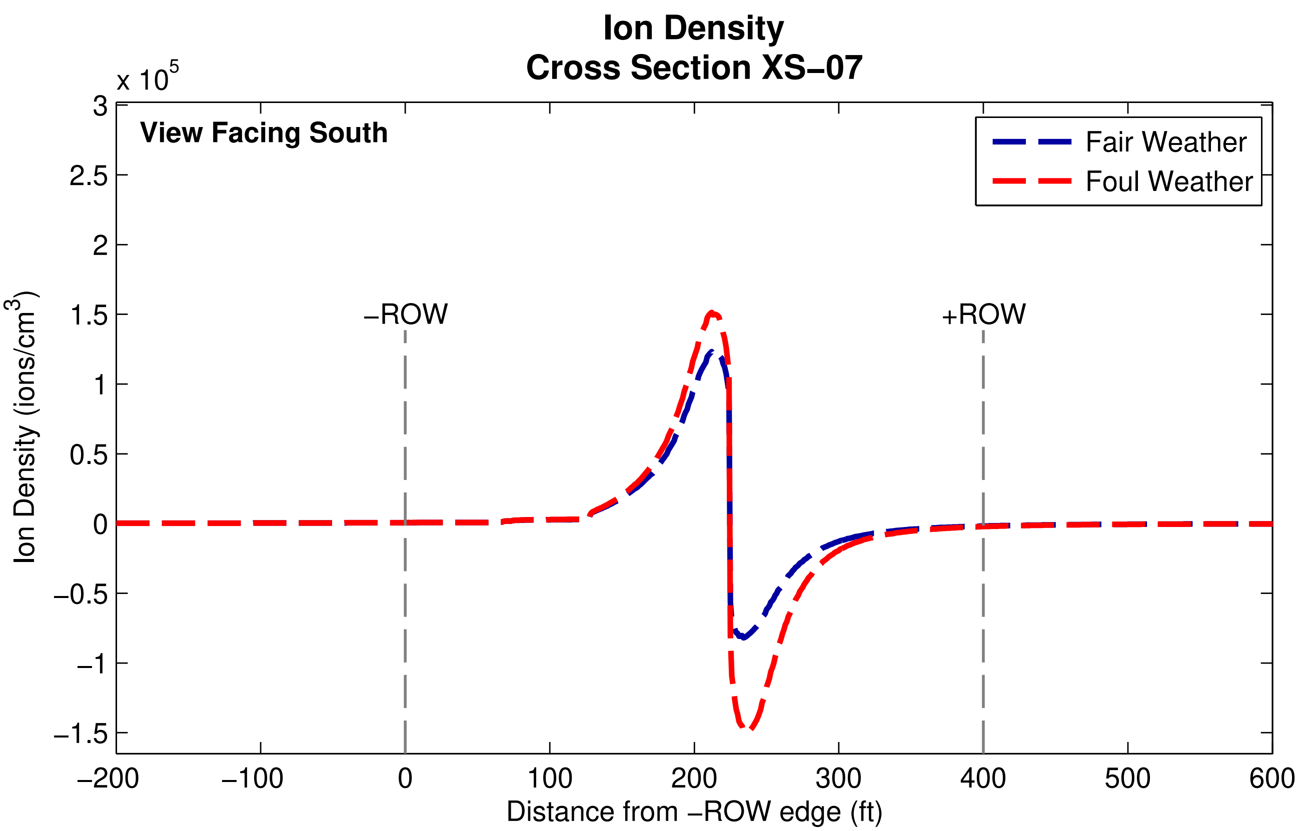

Figure B-21. Calculated post-project ion density profiles along XS-07. Negative density corresponds to density of negative ions

Appendix C

Graphical Profiles of Calculated AC Electric and Magnetic Fields

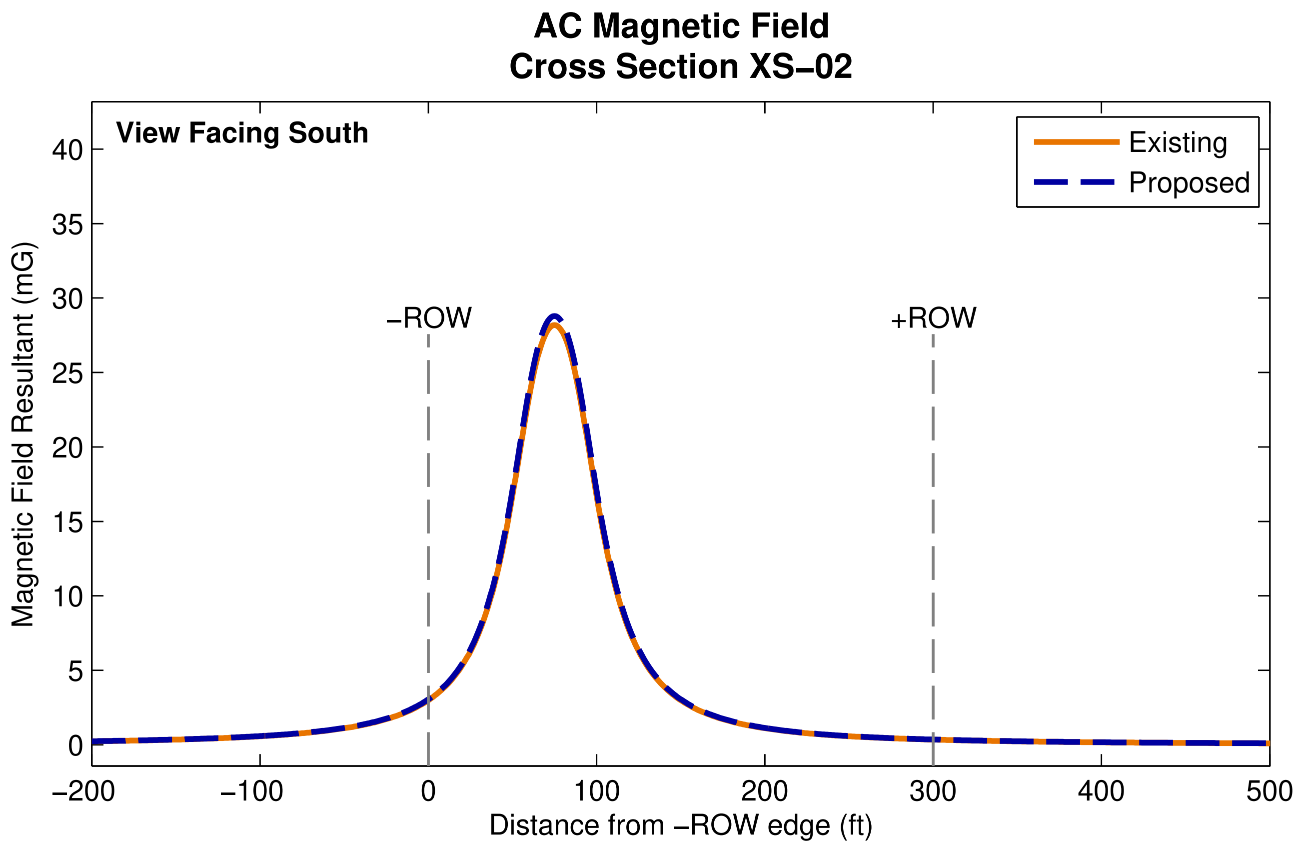

Figure C-1. Calculated AC magnetic-field profiles for average loading along XS-02.

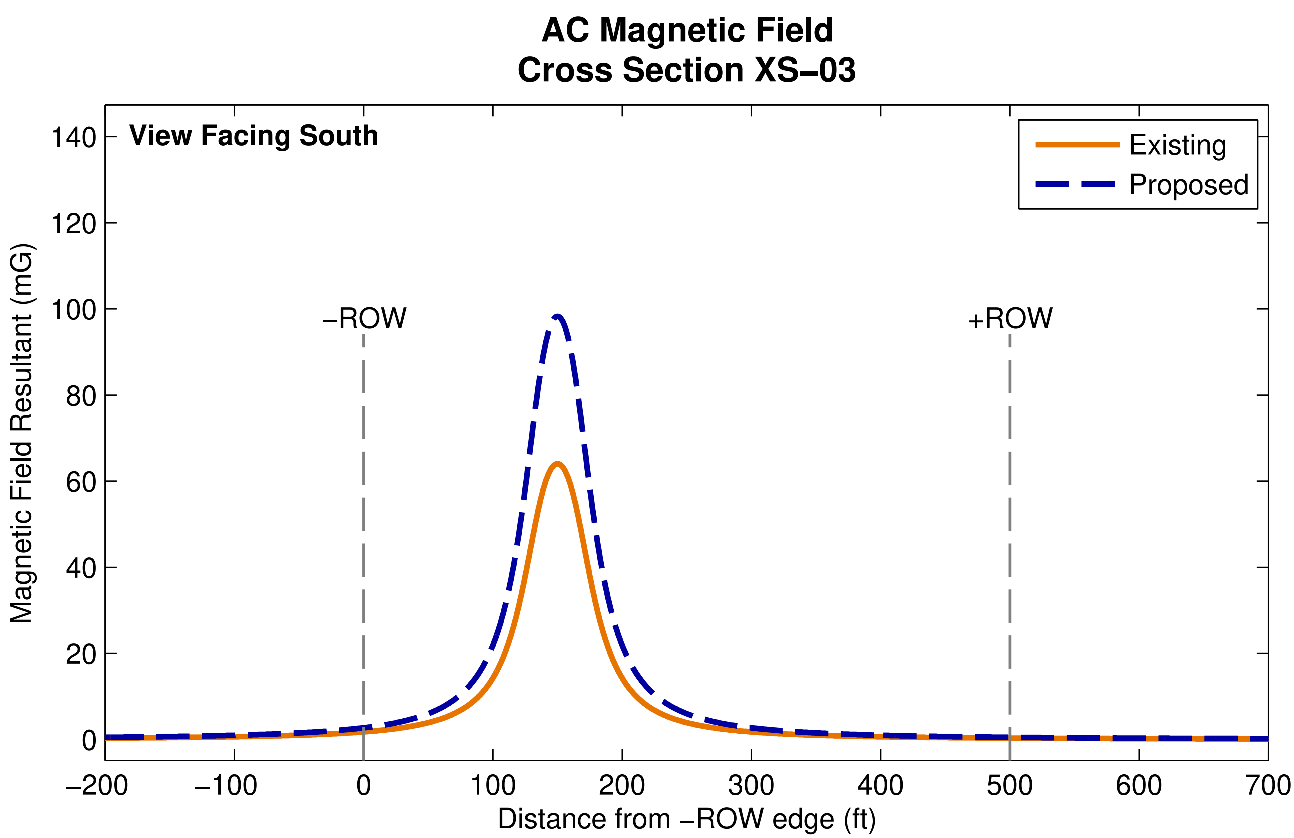

Figure C-2. Calculated AC magnetic-field profiles for average loading along XS-03.

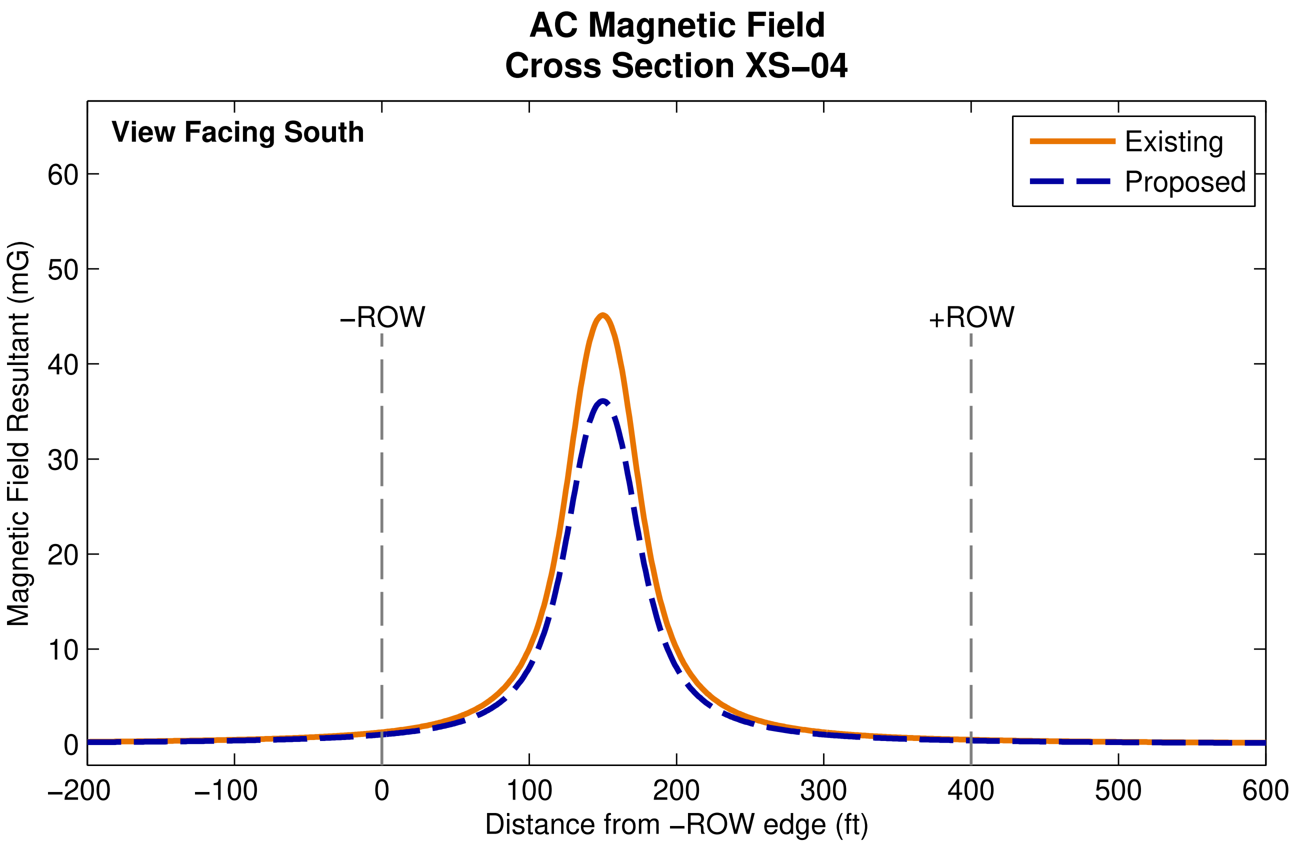

Figure C-3. Calculated AC magnetic-field profiles for average loading along XS-04.

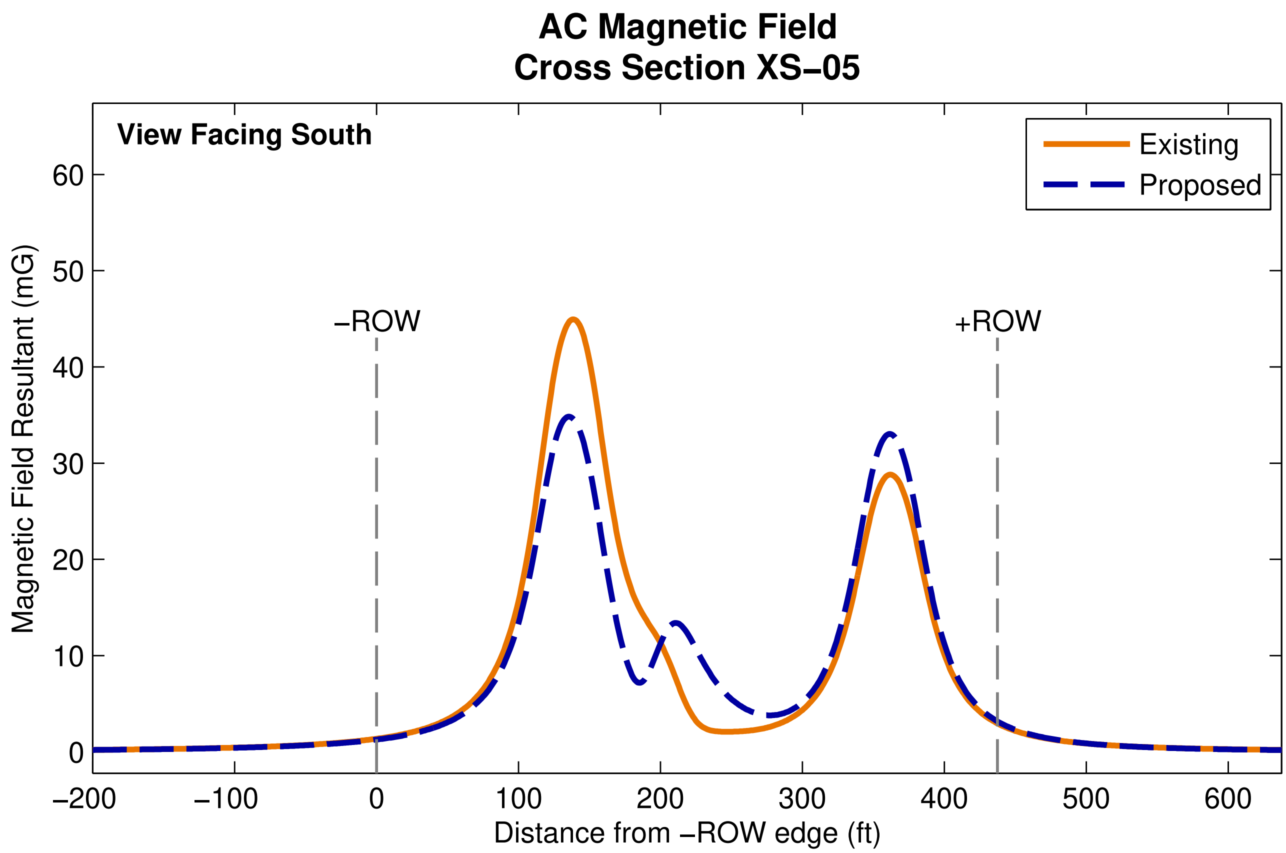

Figure C-4. Calculated AC magnetic-field profiles for average loading along XS-05.

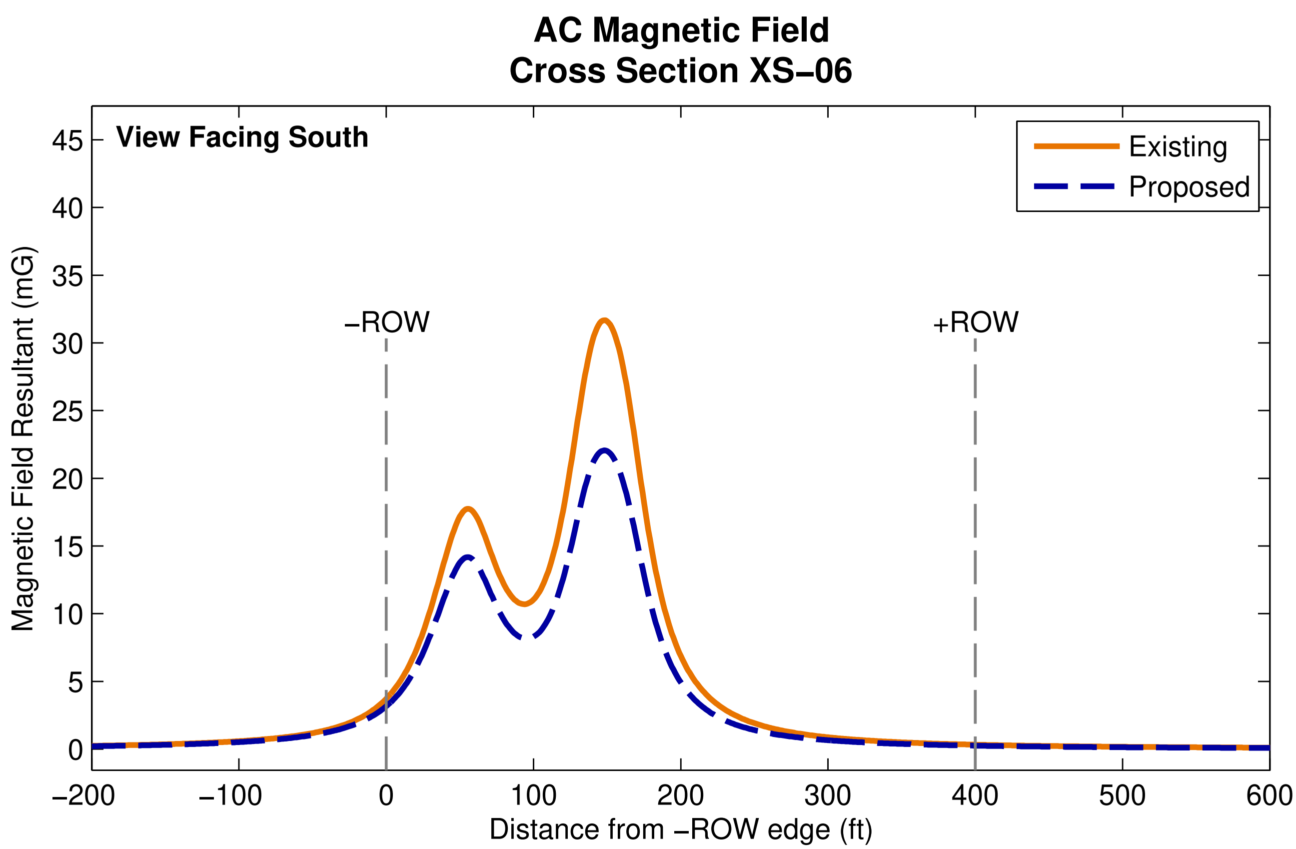

Figure C-5. Calculated AC magnetic-field profiles for average loading along XS-06.

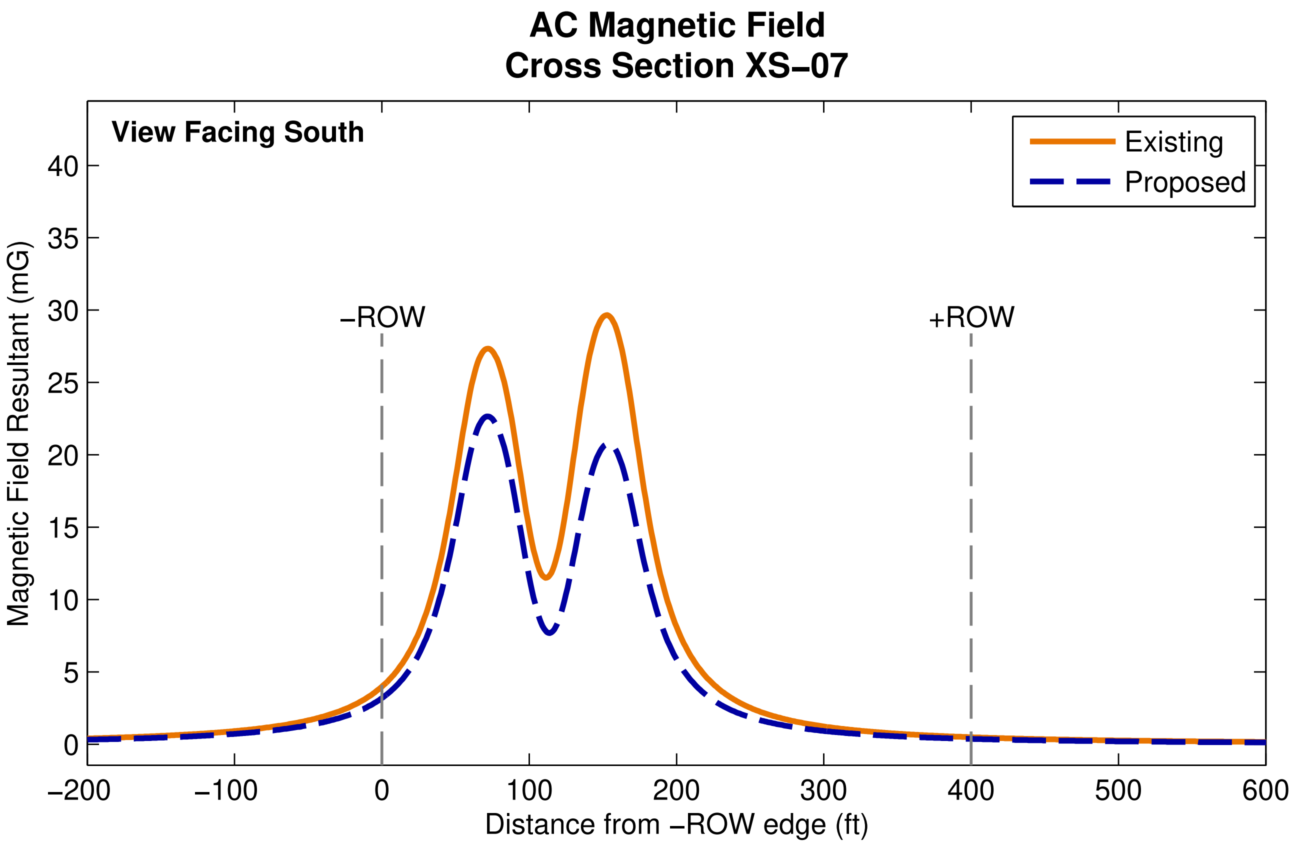

Figure C-6. Calculated AC magnetic-field profiles for average loading along XS-07.

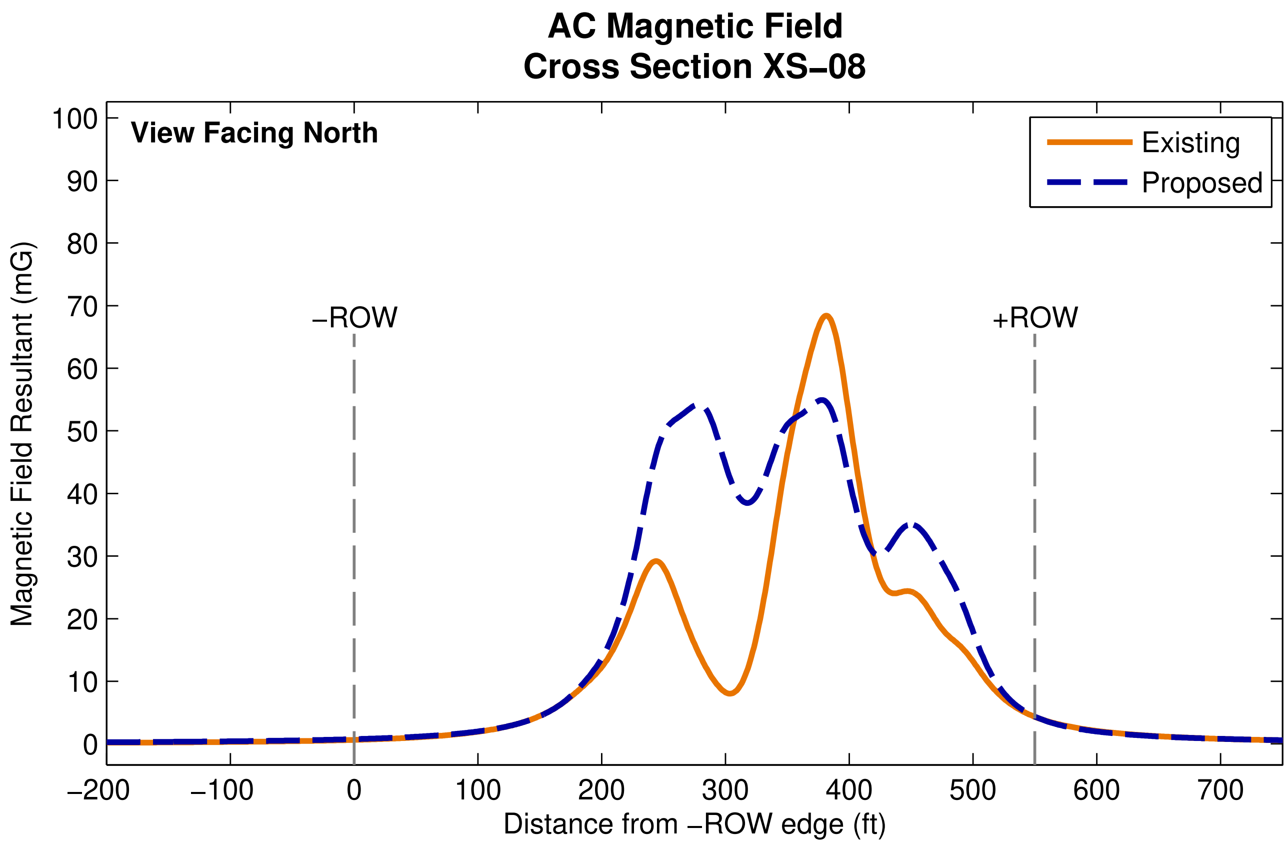

Figure C-7. Calculated AC magnetic-field profiles for average loading along XS-08.

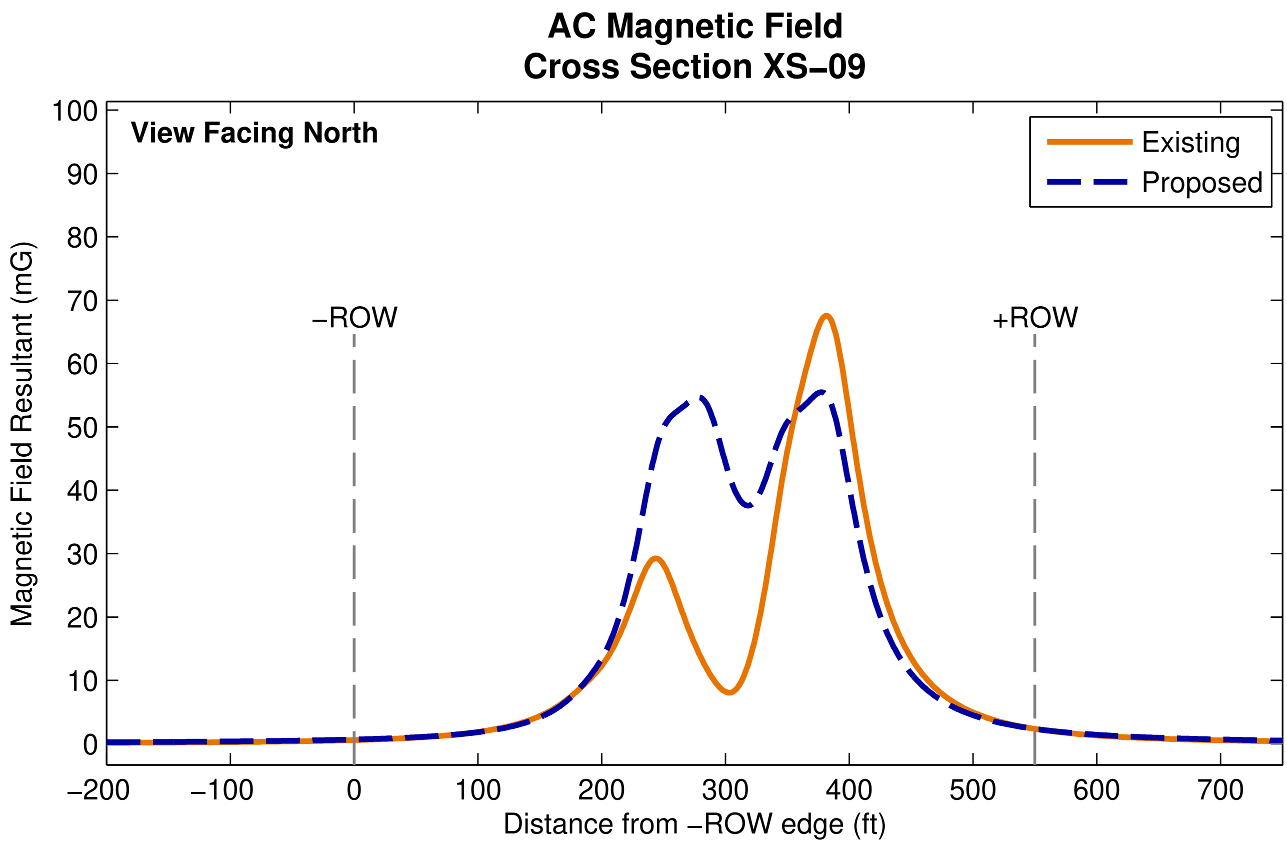

Figure C-8. Calculated AC magnetic-field profiles for average loading along XS-09.

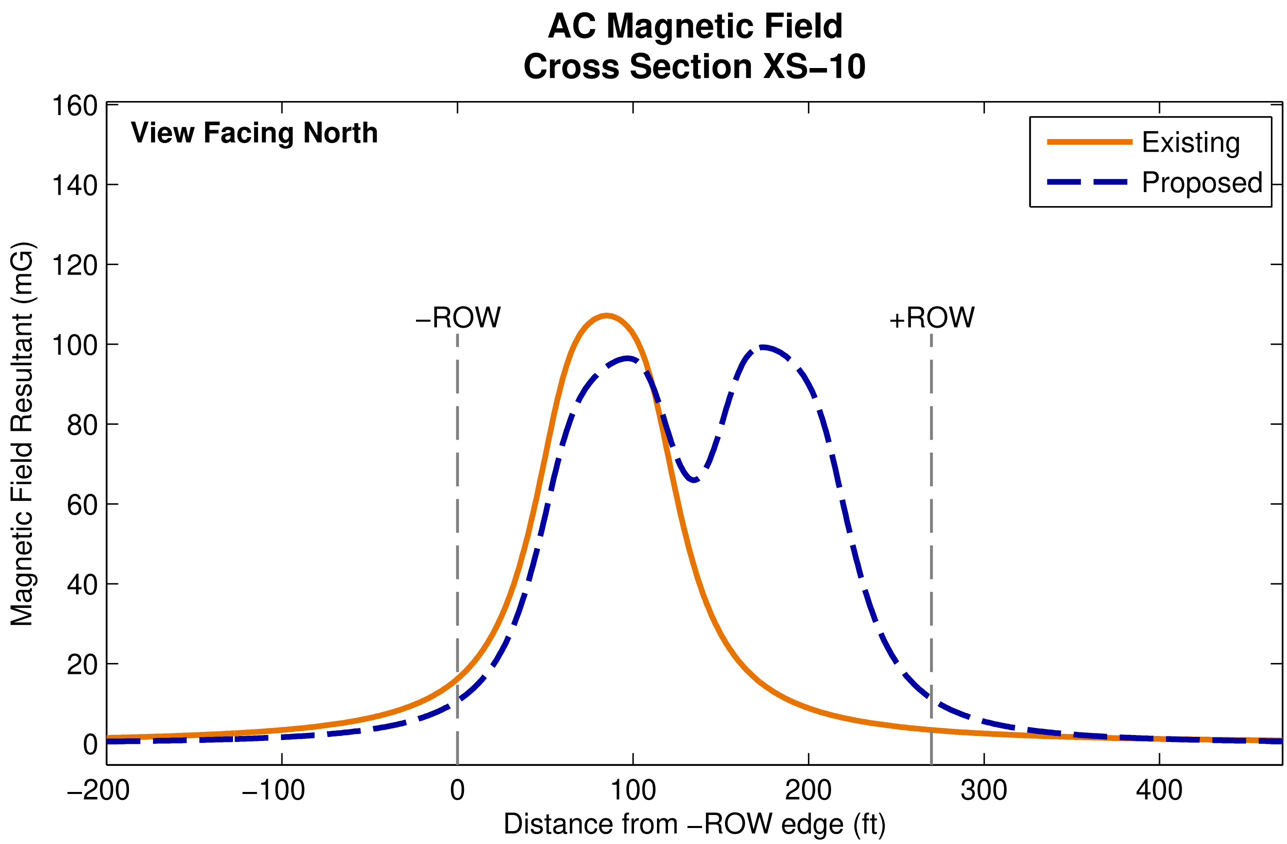

Figure C-9. Calculated AC magnetic-field profiles for average loading along XS-10.

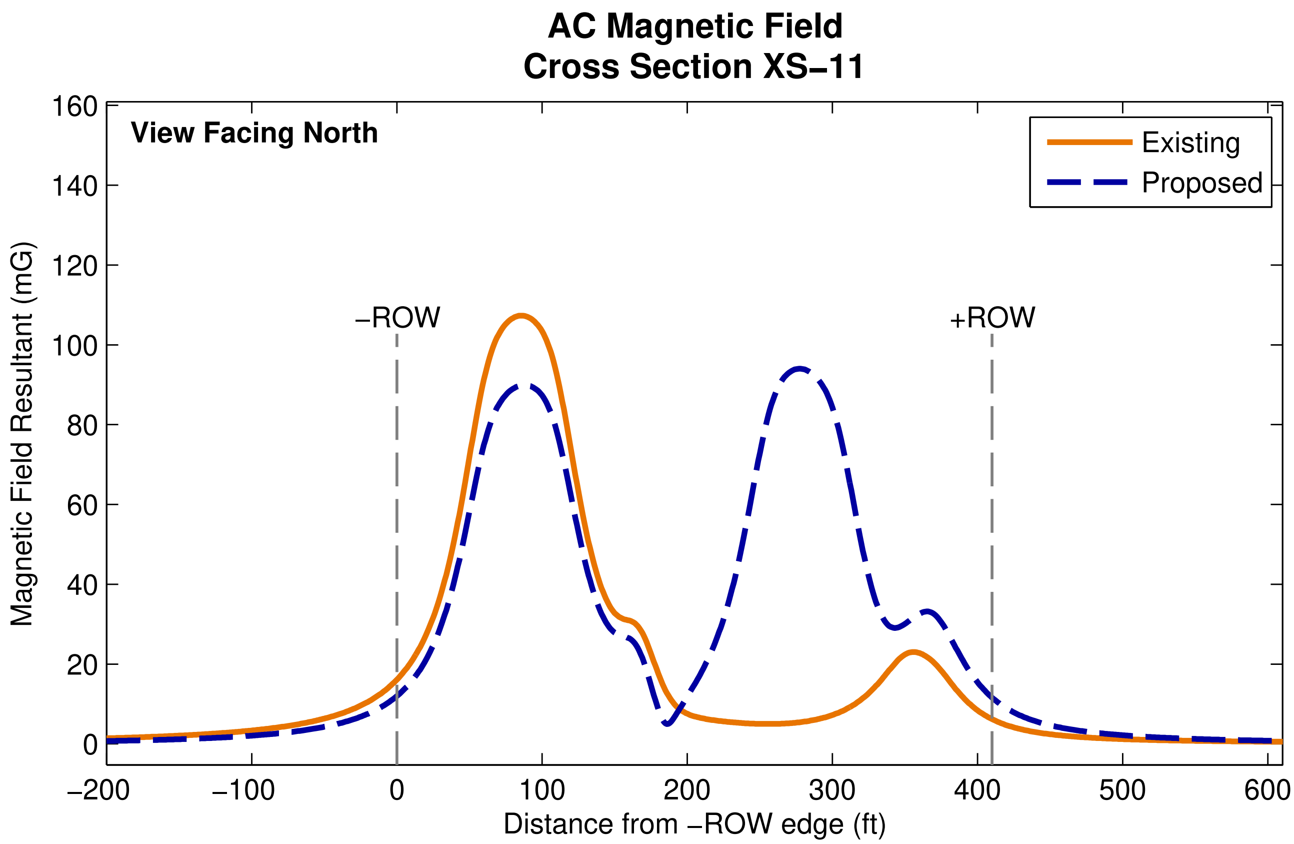

Figure C-10. Calculated AC magnetic-field profiles for average loading along XS-11.

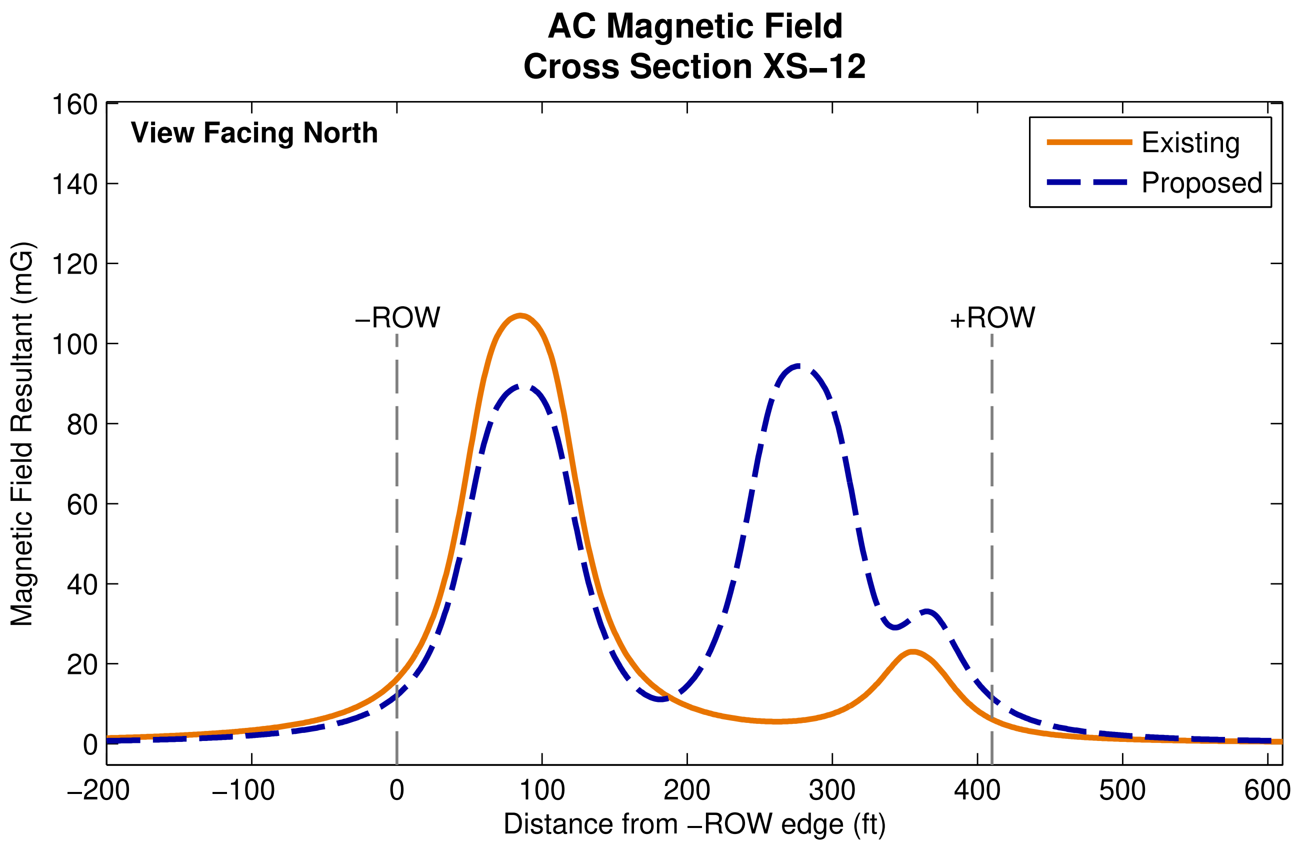

Figure C-11. Calculated AC magnetic-field profiles for average loading along XS-12.

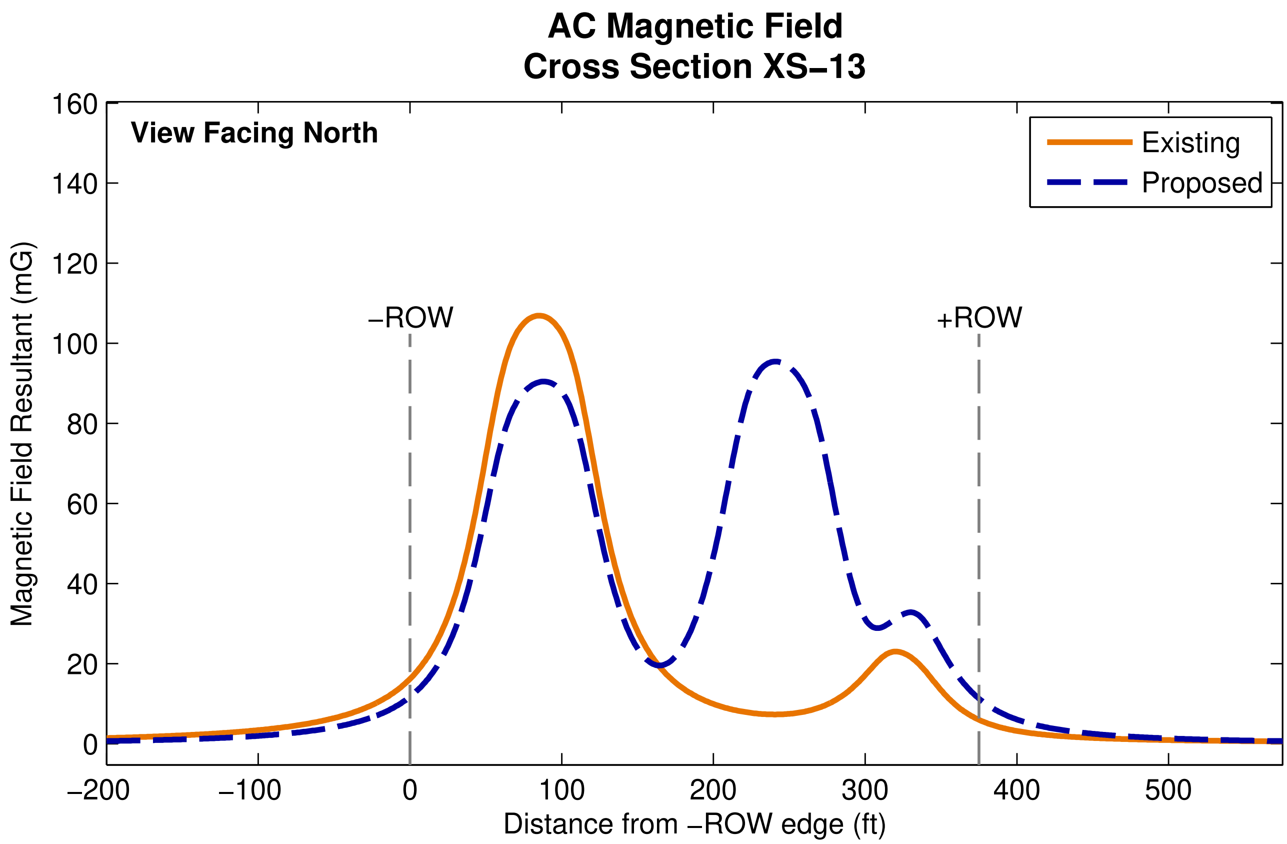

Figure C-12. Calculated AC magnetic-field profiles for average loading along XS-13.

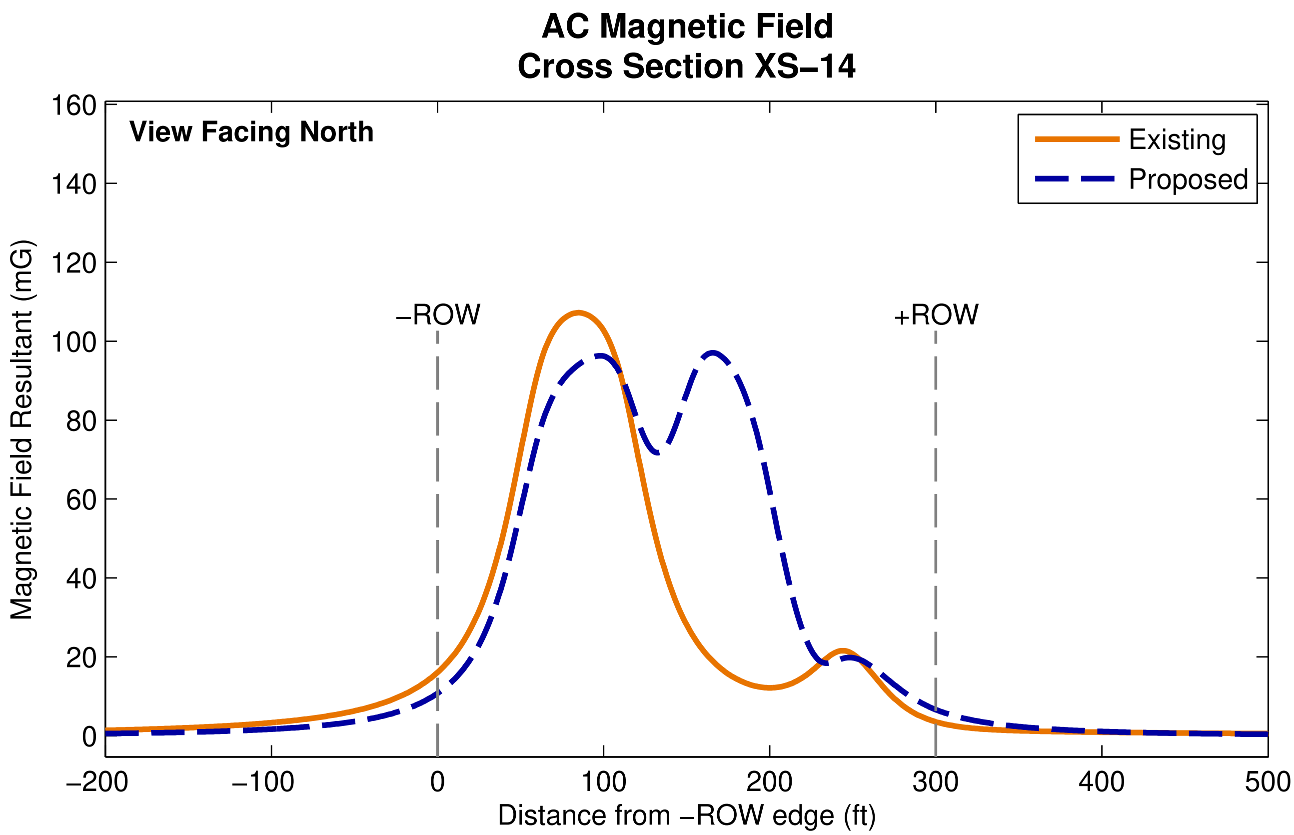

Figure C-13. Calculated AC magnetic-field profiles for average loading along XS-14.

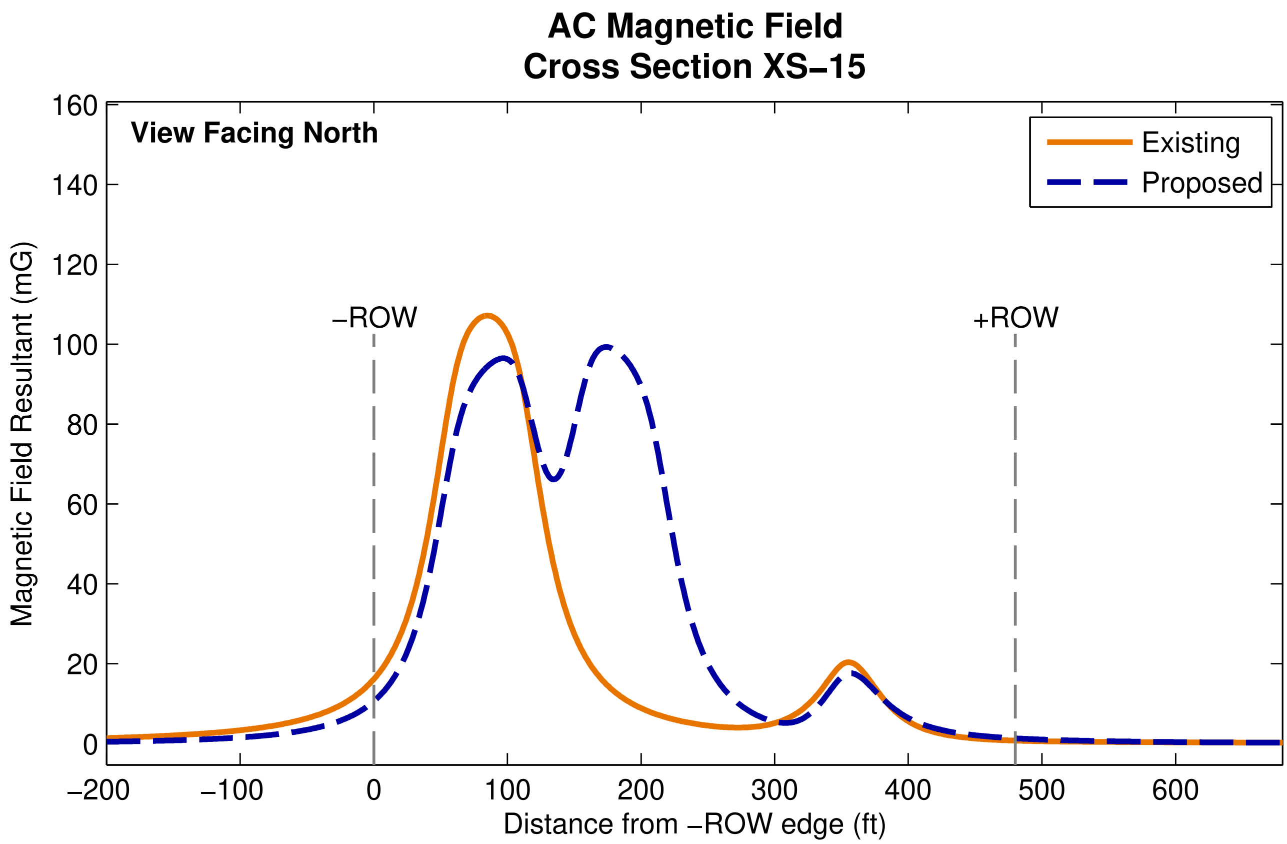

Figure C-14. Calculated AC magnetic-field profiles for average loading along XS-15.

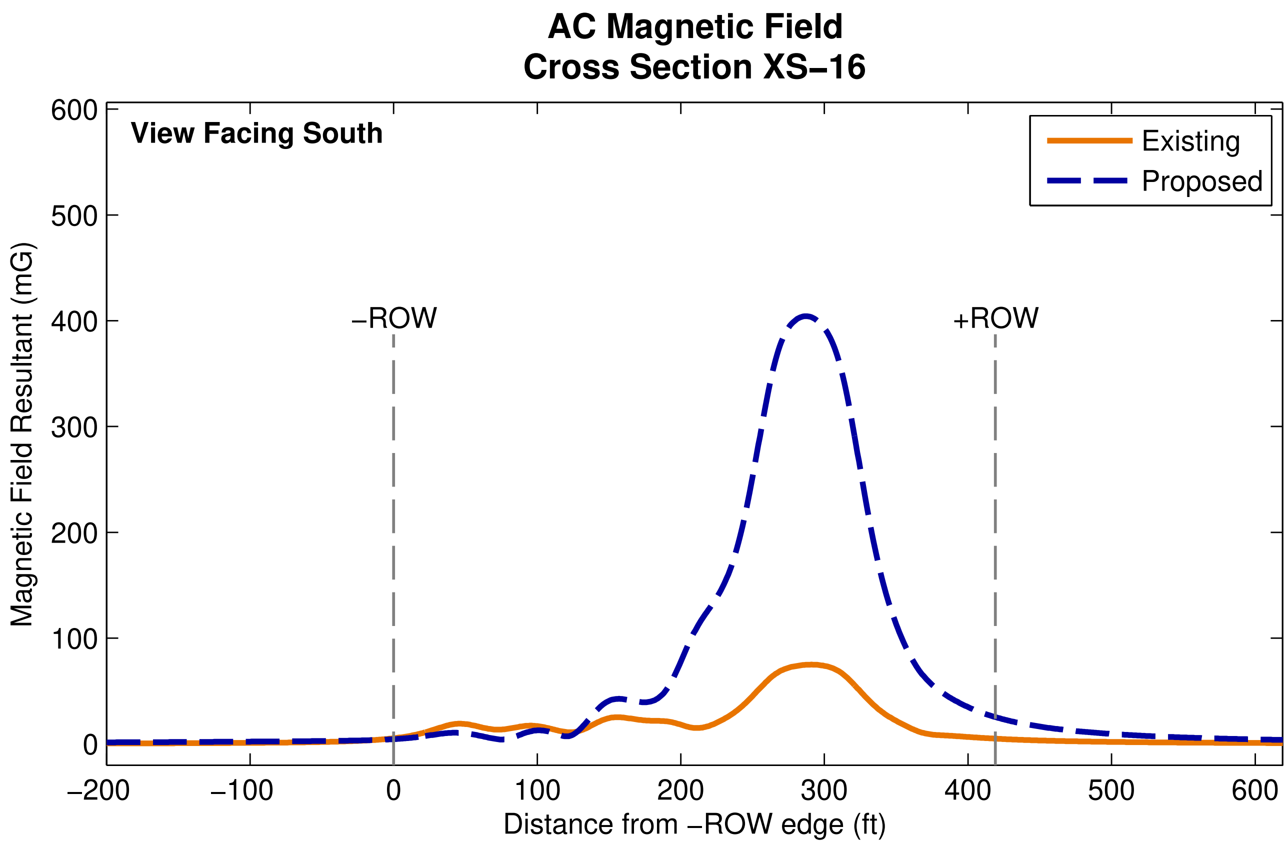

Figure C-15. Calculated AC magnetic-field profiles for average loading along XS-16.

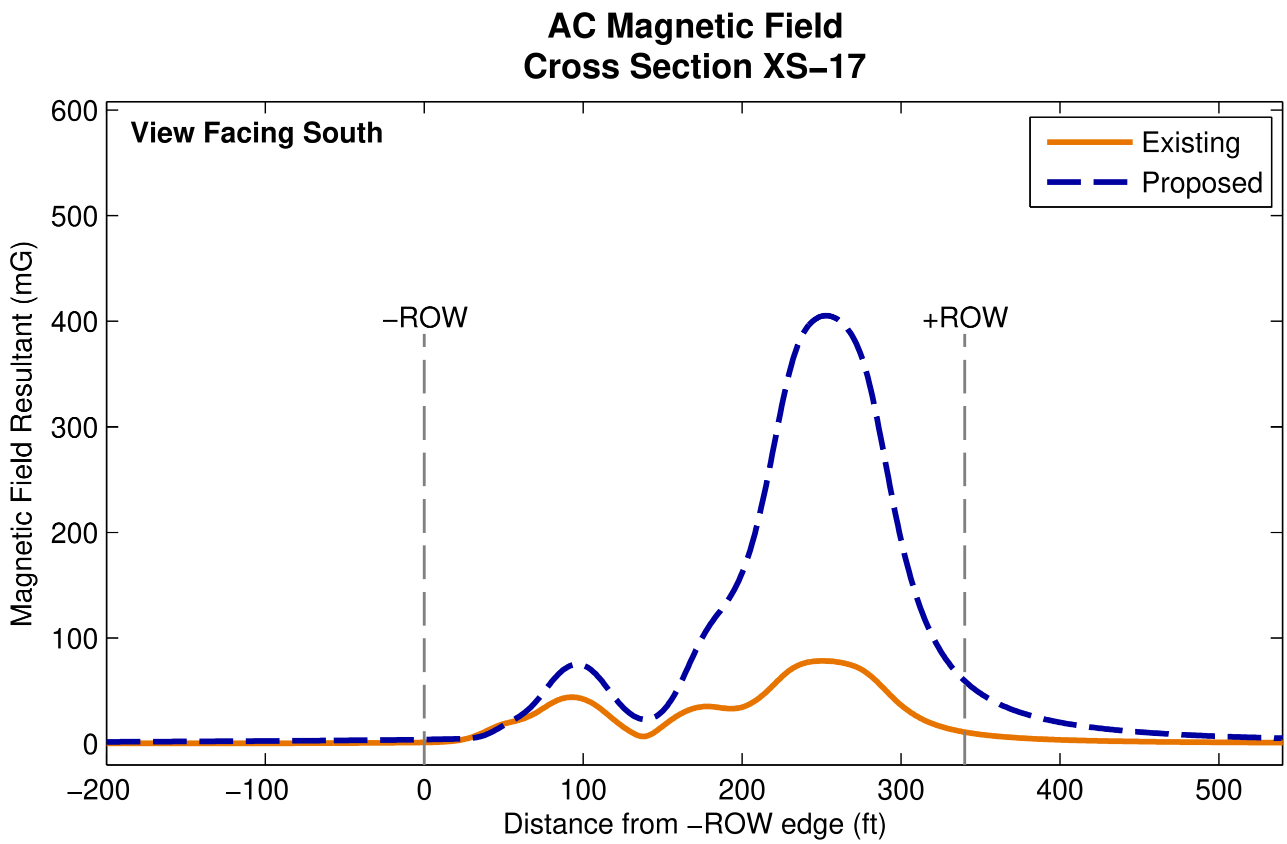

Figure C-16. Calculated AC magnetic-field profiles for average loading along XS-17.

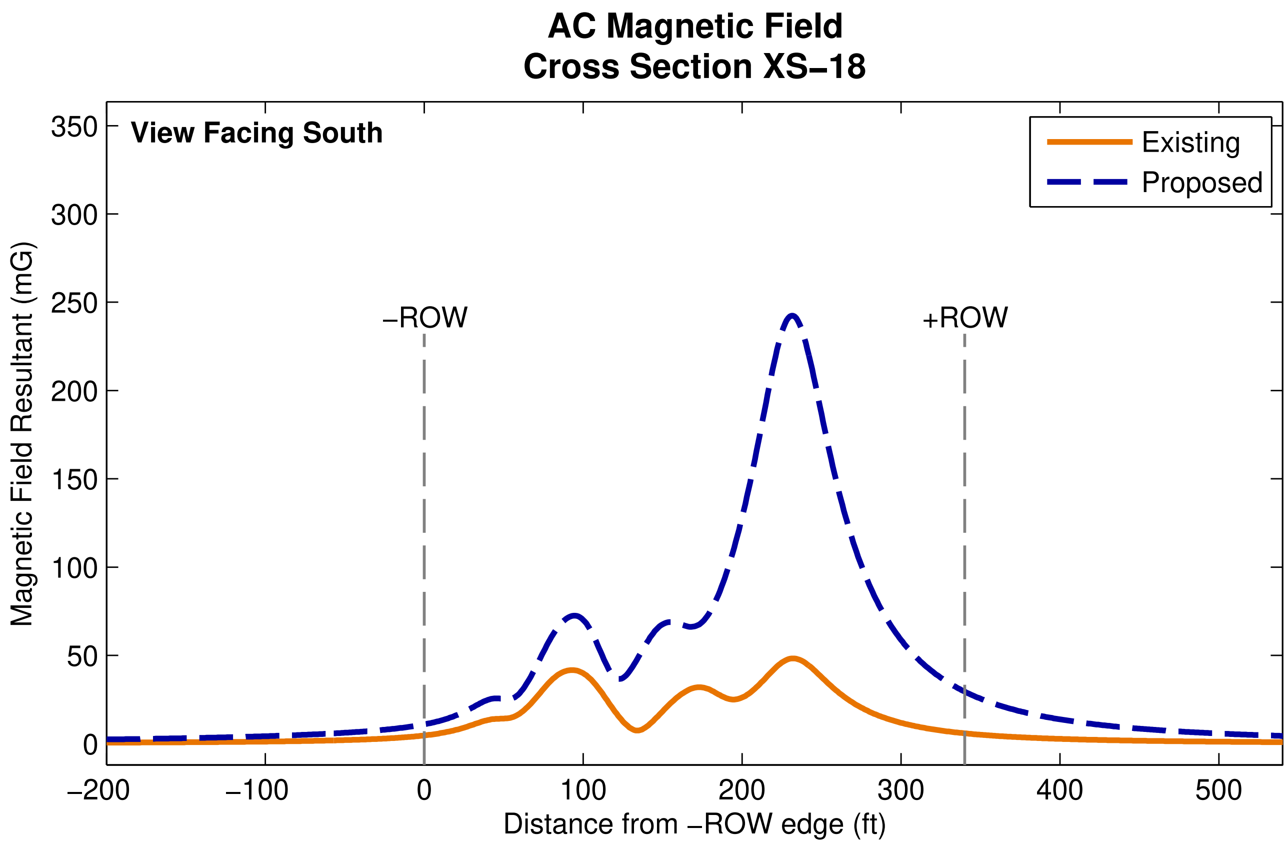

Figure C-17. Calculated AC magnetic-field profiles for average loading along XS-18.

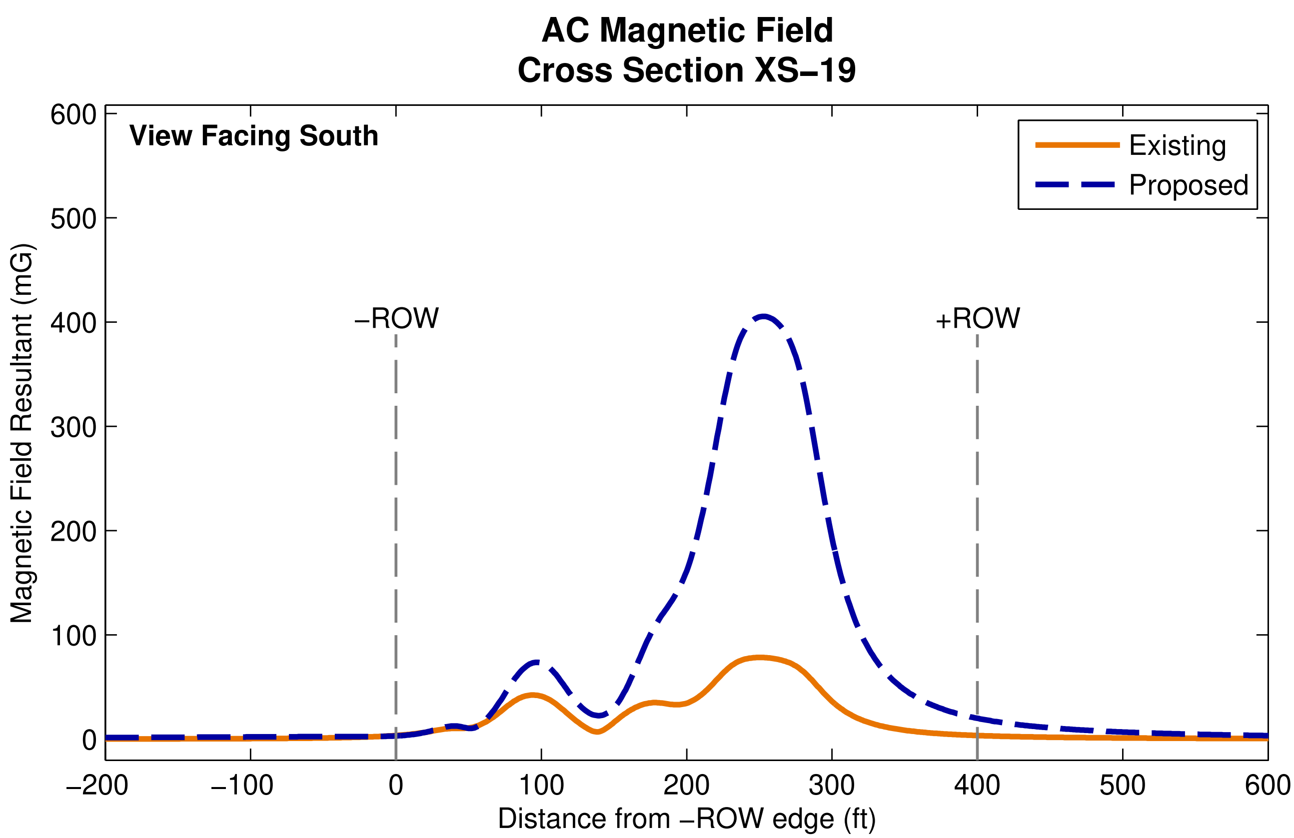

Figure C-18. Calculated AC magnetic-field profiles for average loading along XS-19.

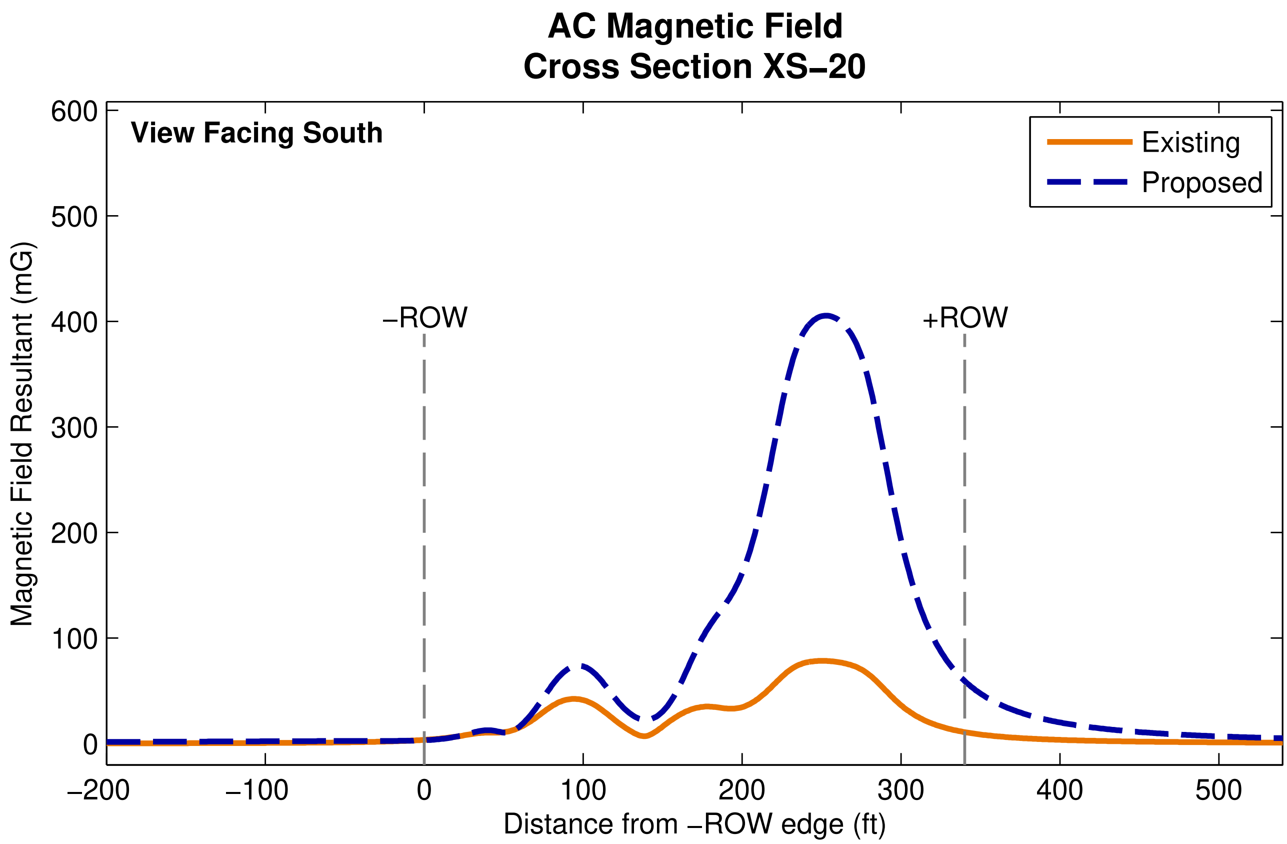

Figure C-19. Calculated AC magnetic-field profiles for average loading along XS-20.

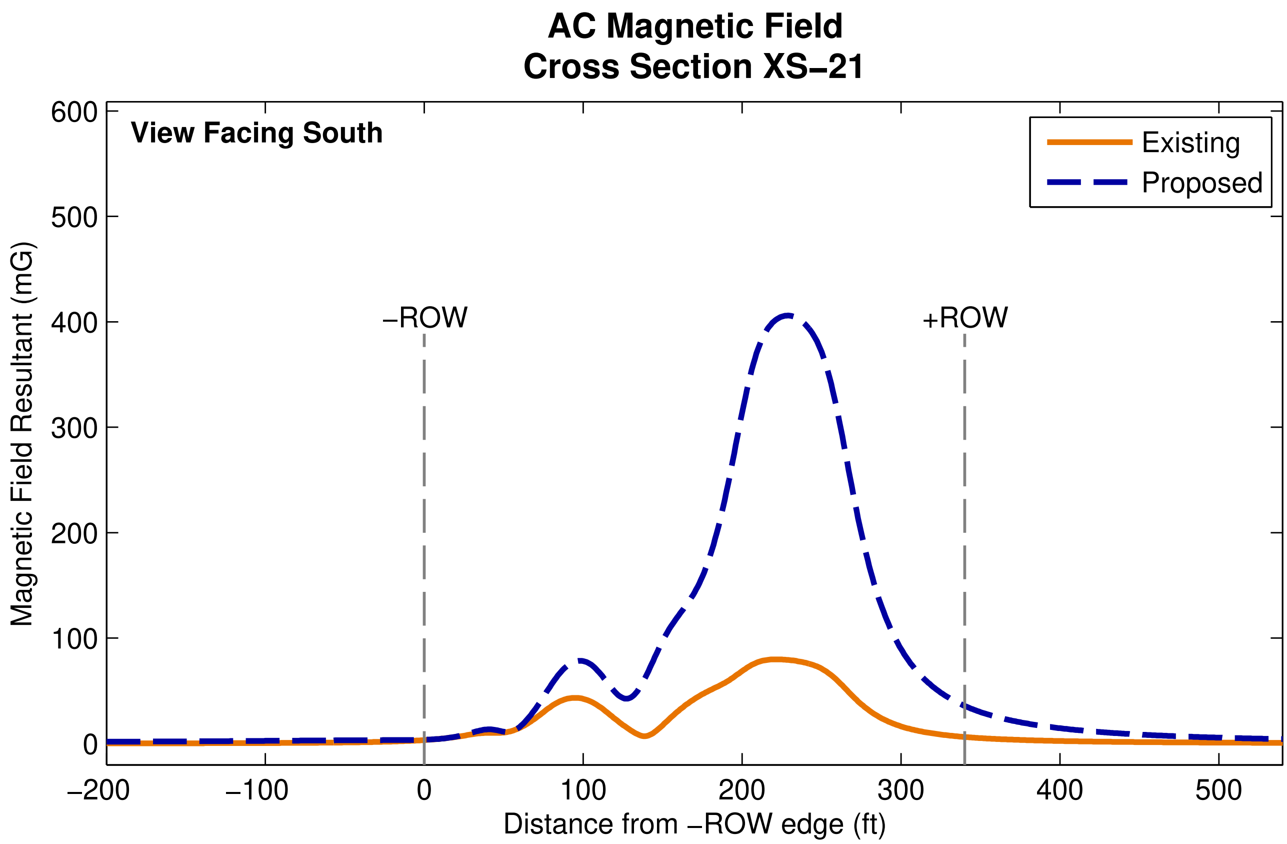

Figure C-20. Calculated AC magnetic-field profiles for average loading along XS-21.

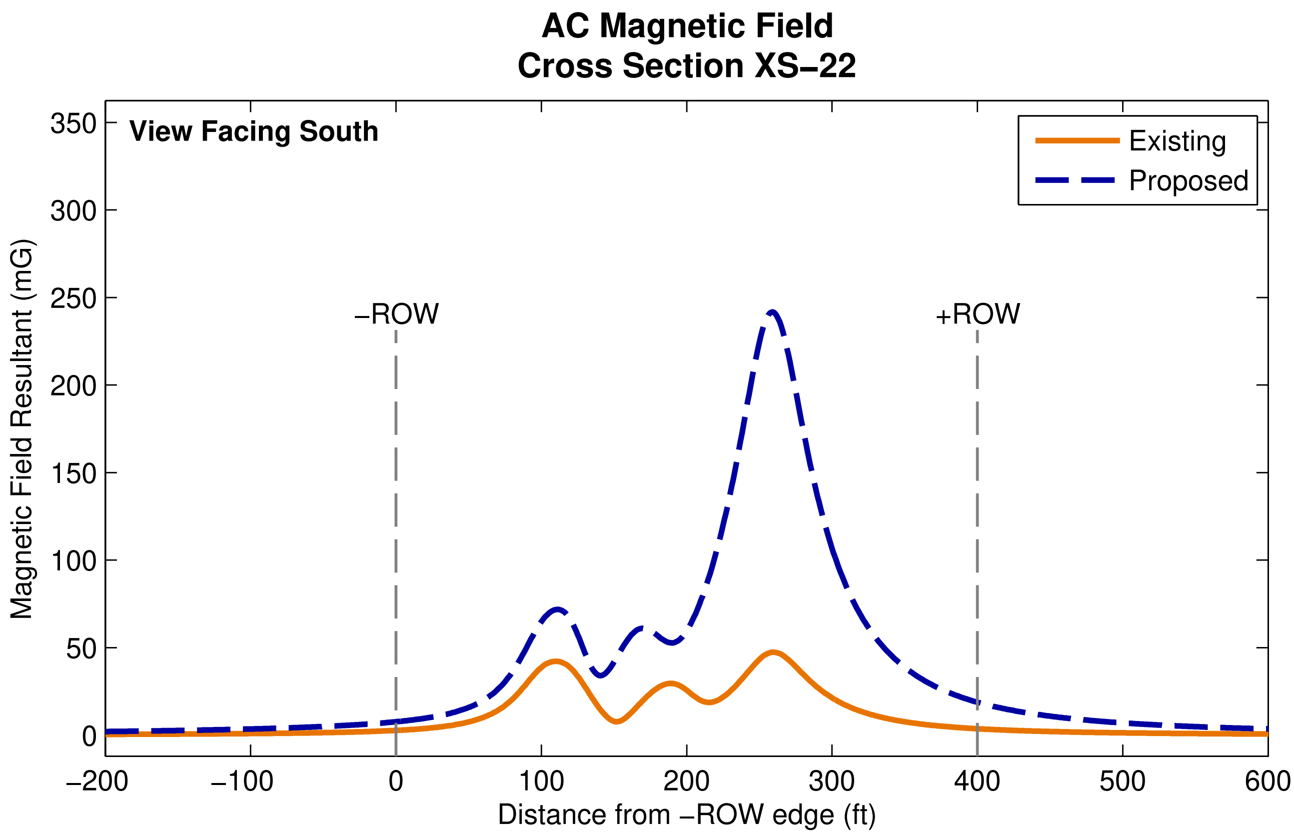

Figure C-21. Calculated AC magnetic-field profiles for average loading along XS-22.

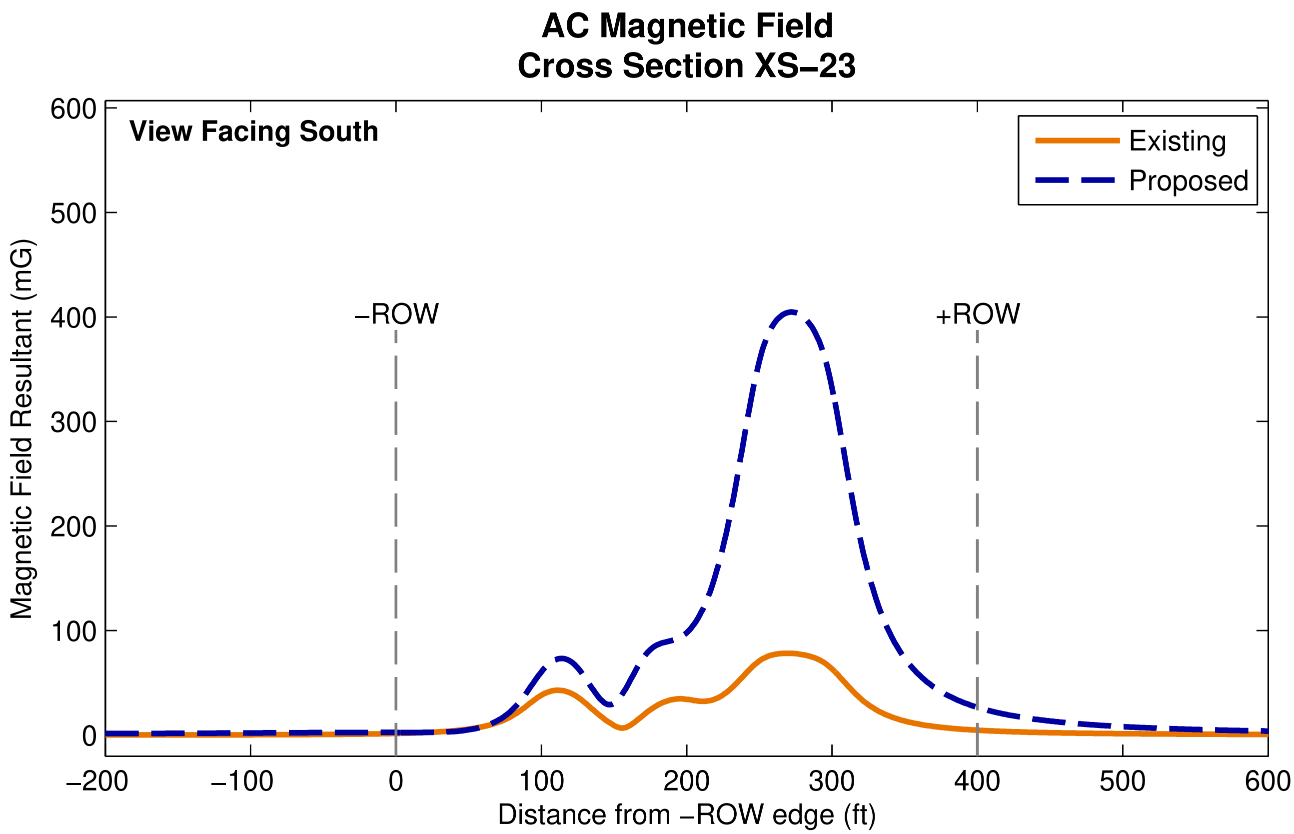

Figure C-22. Calculated AC magnetic-field profiles for average loading along XS-23.

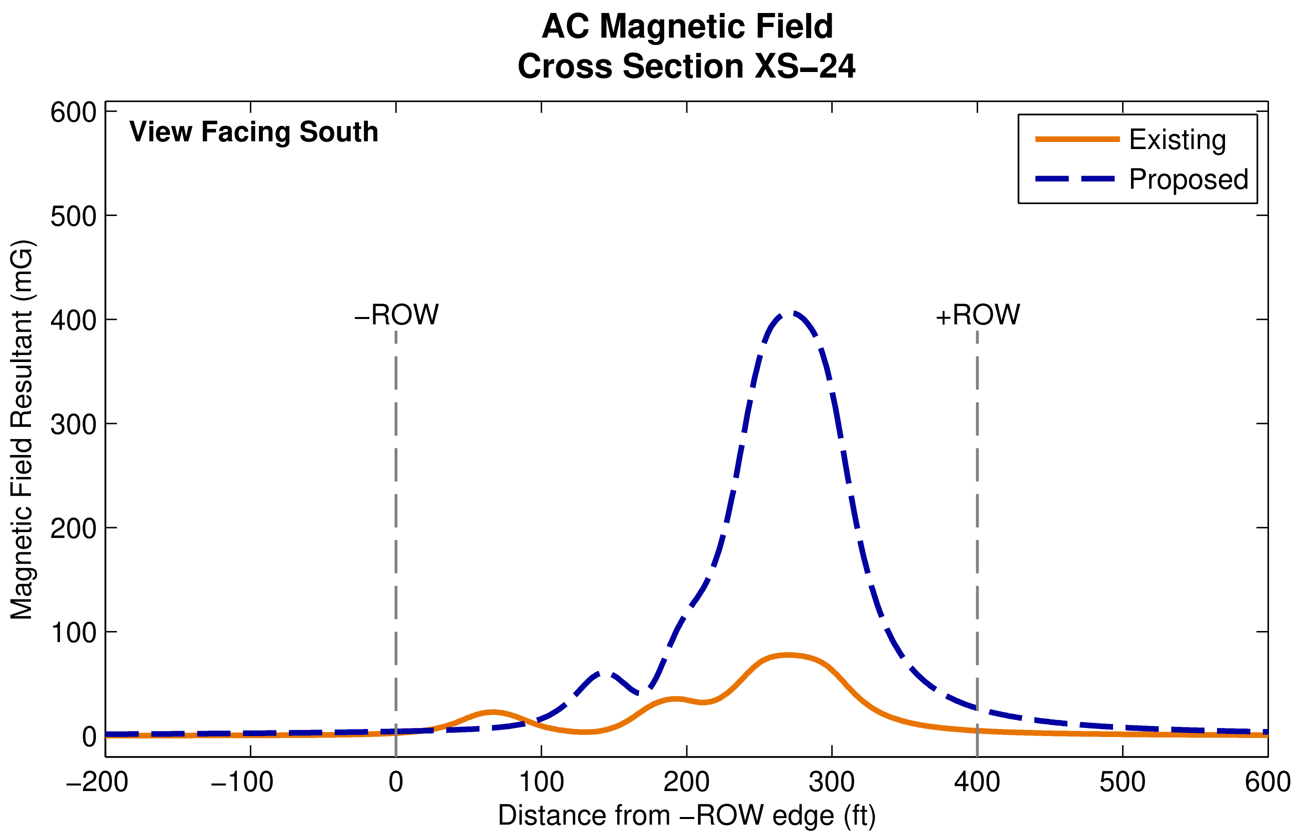

Figure C-23. Calculated AC magnetic-field profiles for average loading along XS-24.

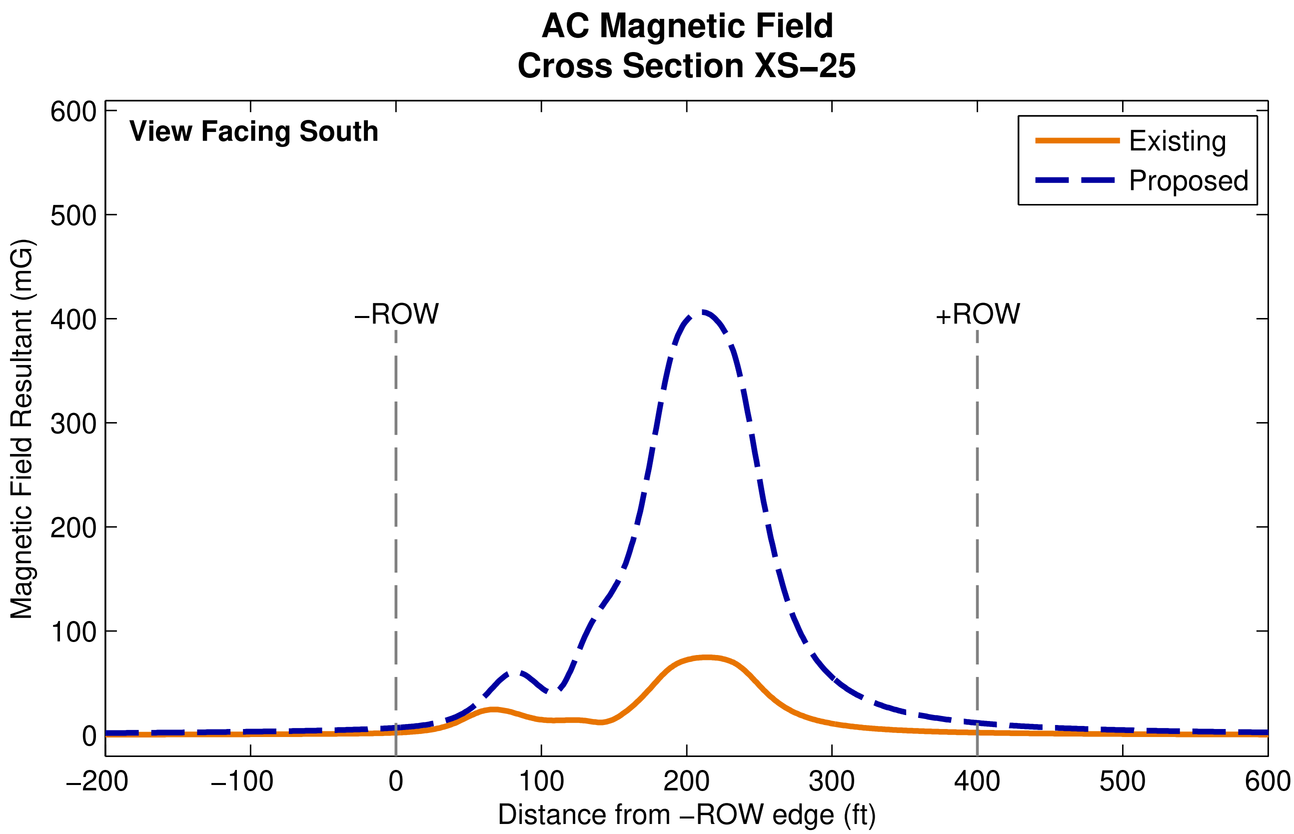

Figure C-24. Calculated AC magnetic-field profiles for average loading along XS-25.

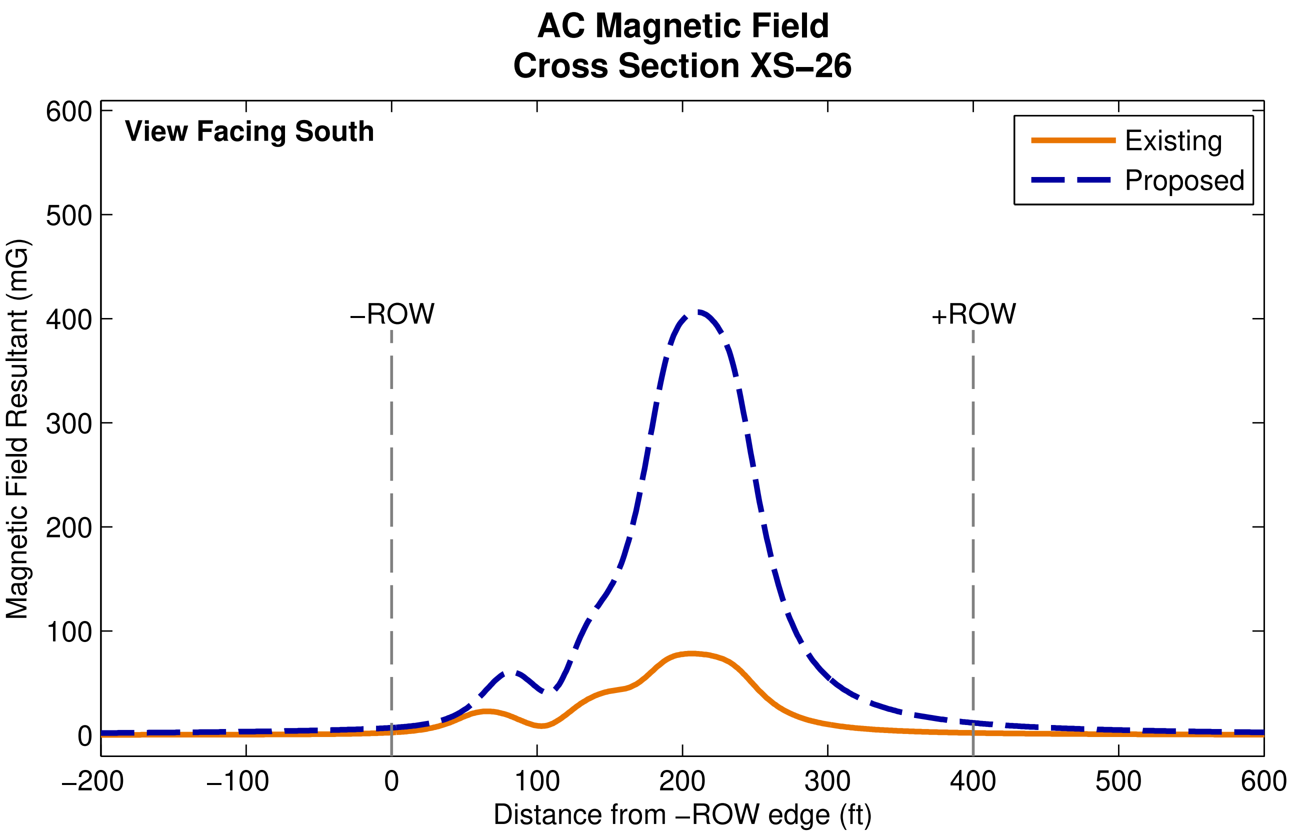

Figure C-25. Calculated AC magnetic-field profiles for average loading along XS-26.

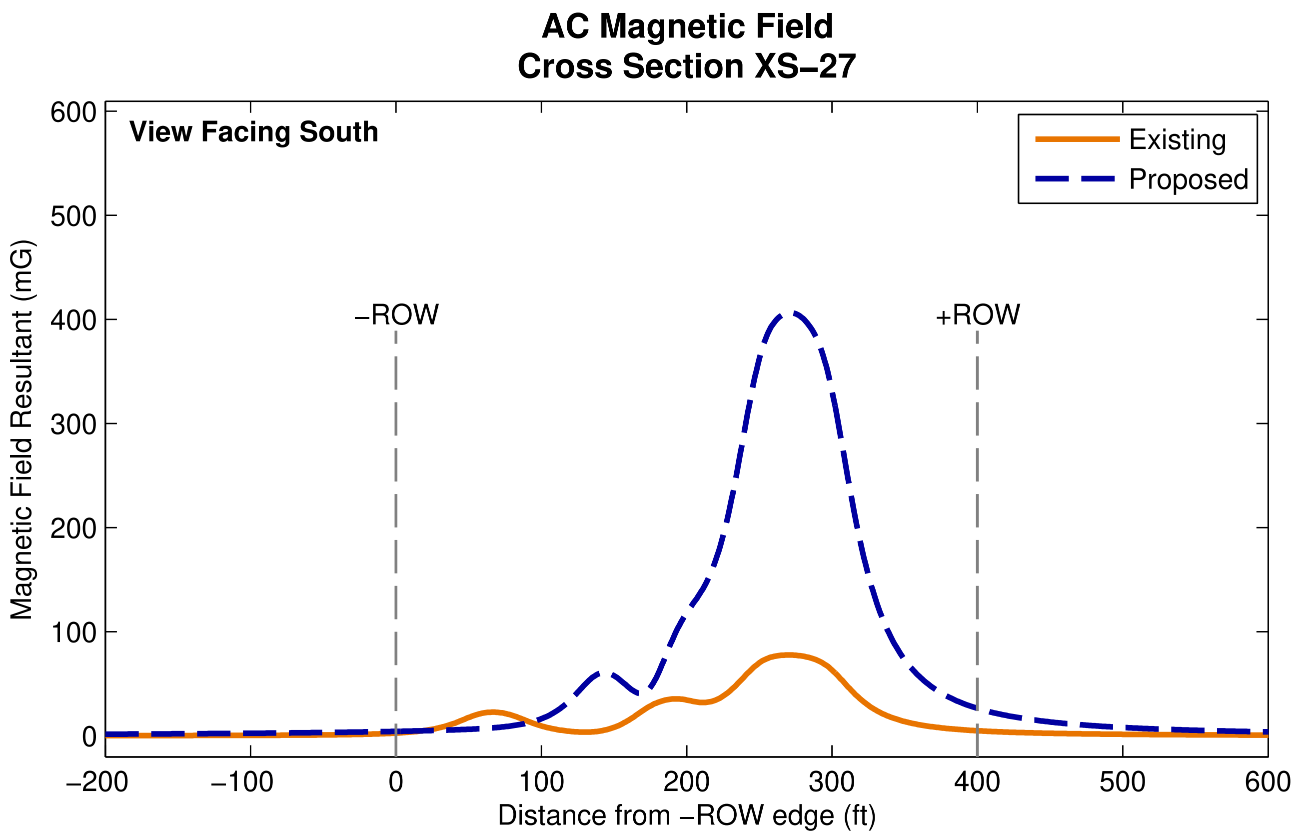

Figure C-26. Calculated AC magnetic-field profiles for average loading along XS-27.

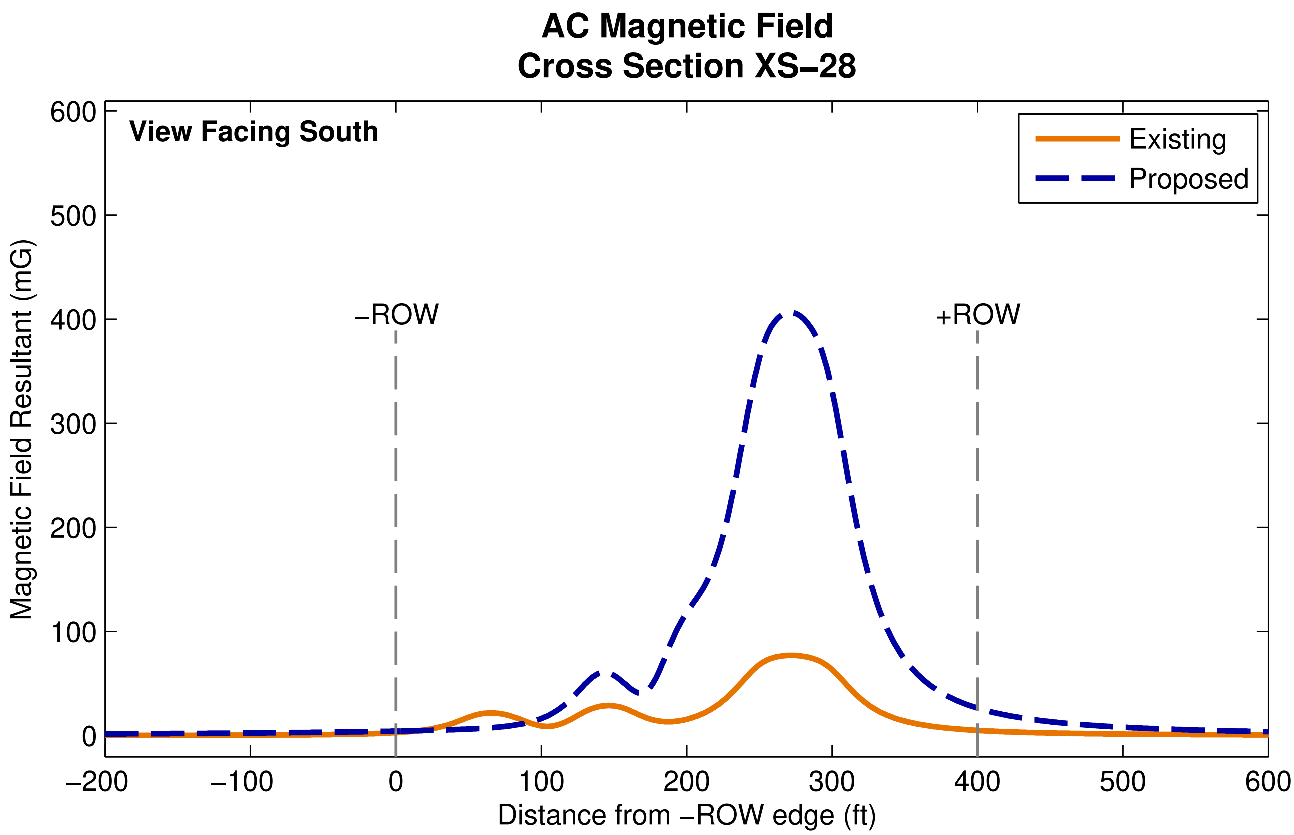

Figure C-27. Calculated AC magnetic-field profiles for average loading along XS-28.

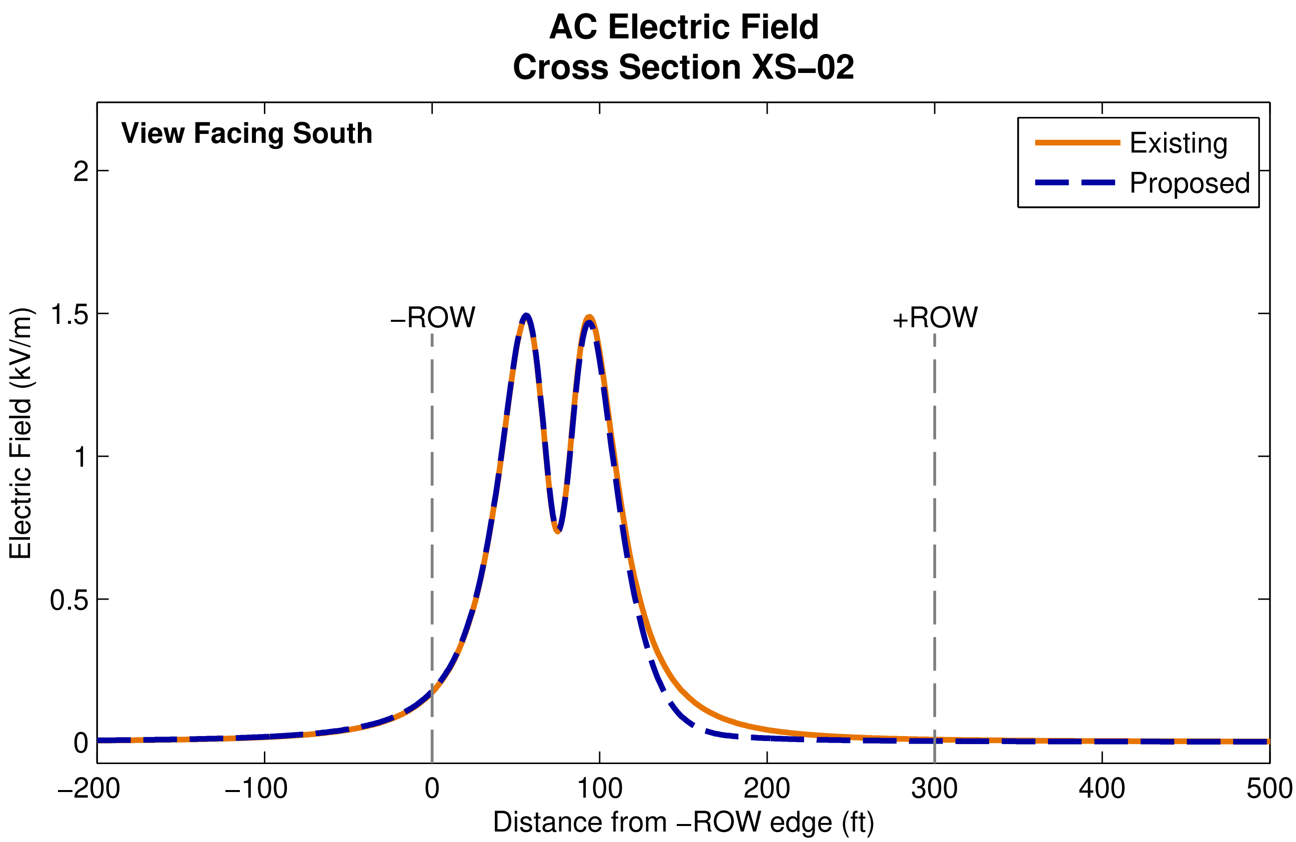

Figure C-28. Calculated AC electric-field profiles along XS-02.

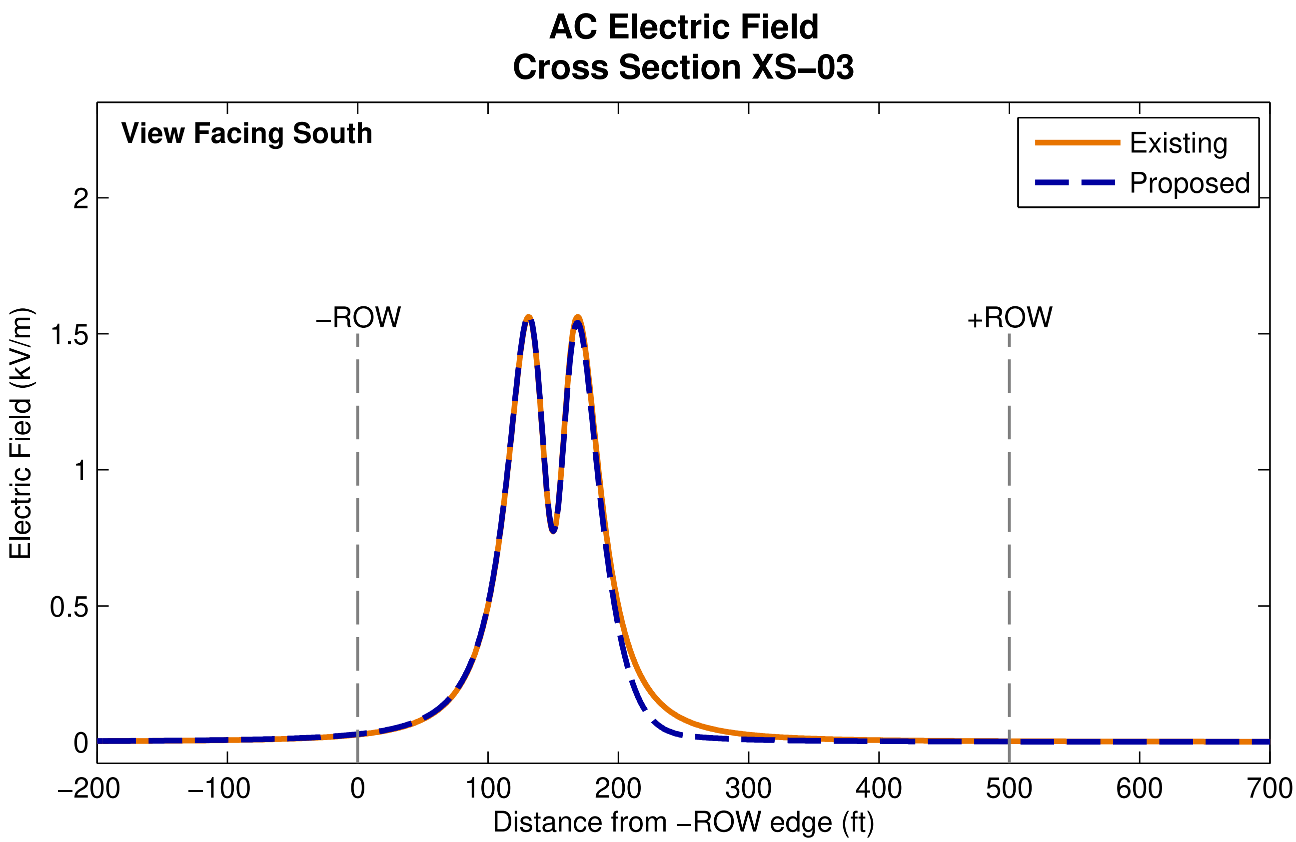

Figure C-29. Calculated AC electric-field profiles along XS-03.

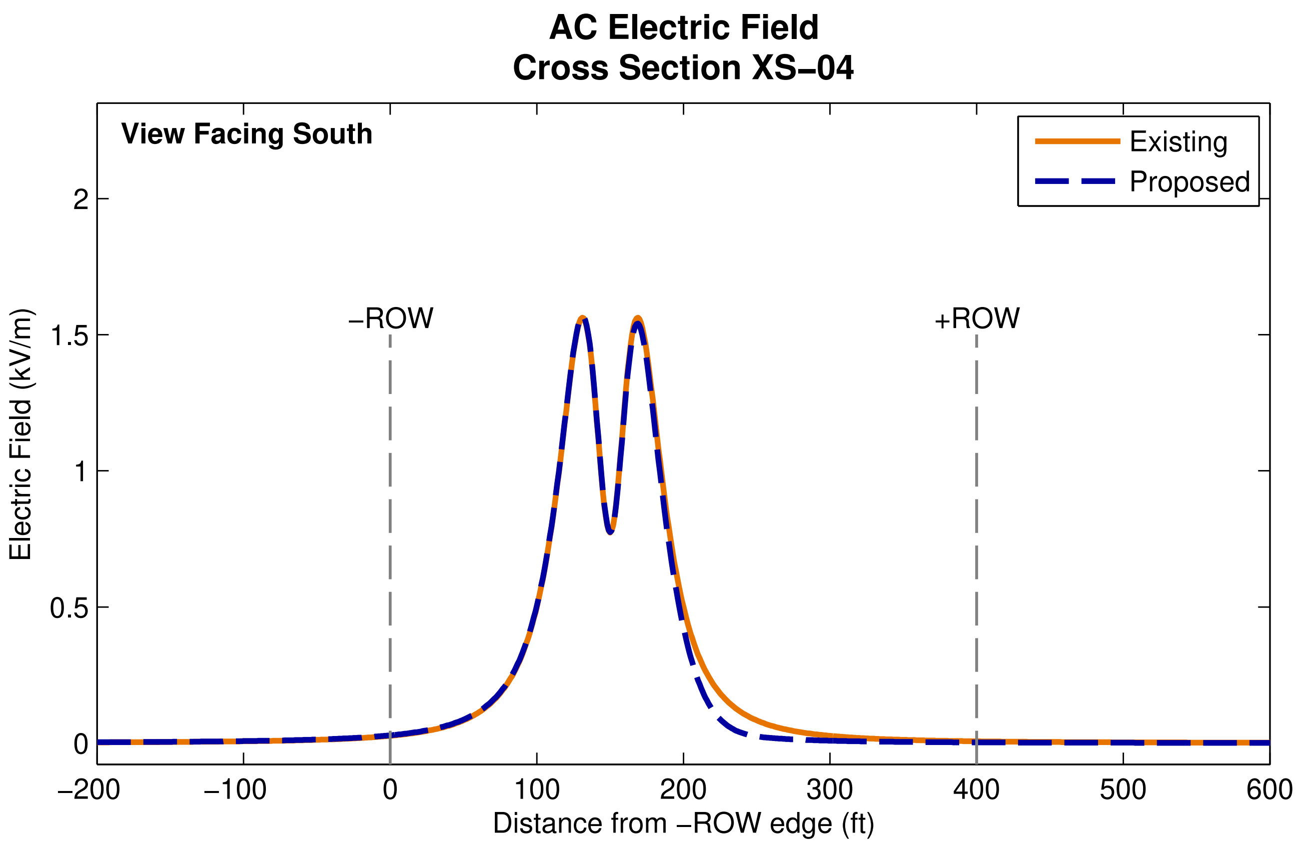

Figure C-30. Calculated AC electric-field profiles along XS-04.

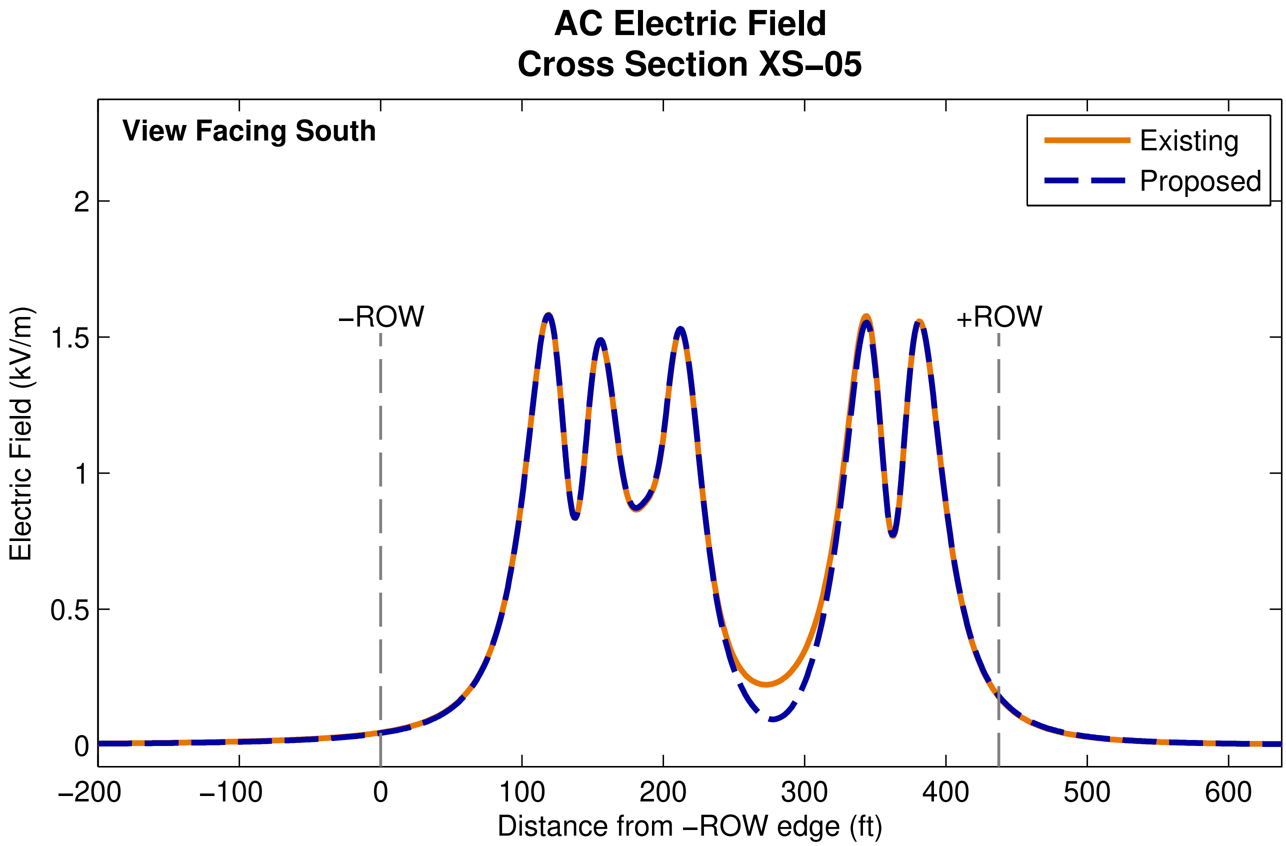

Figure C-31. Calculated AC electric-field profiles along XS-05.

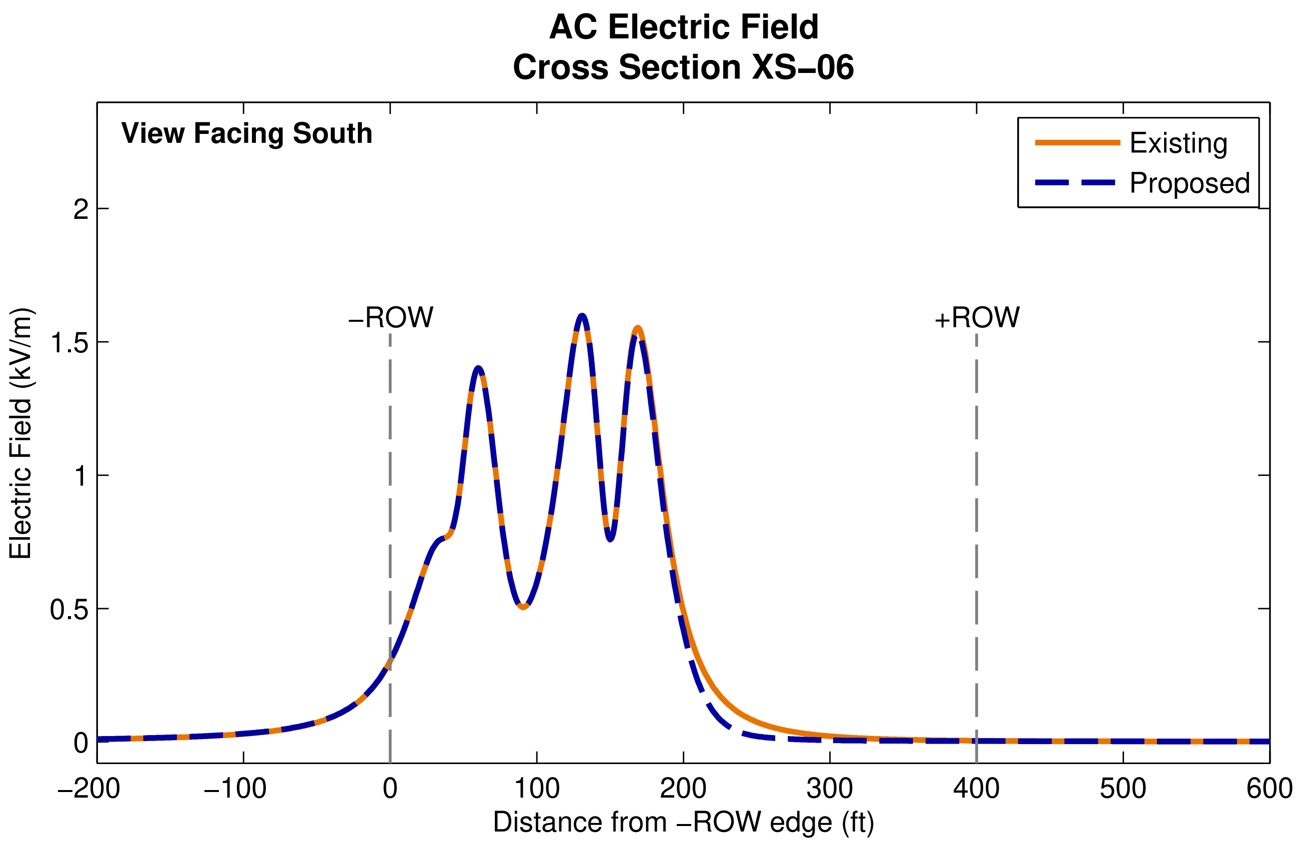

Figure C-32. Calculated AC electric-field profiles along XS-06.

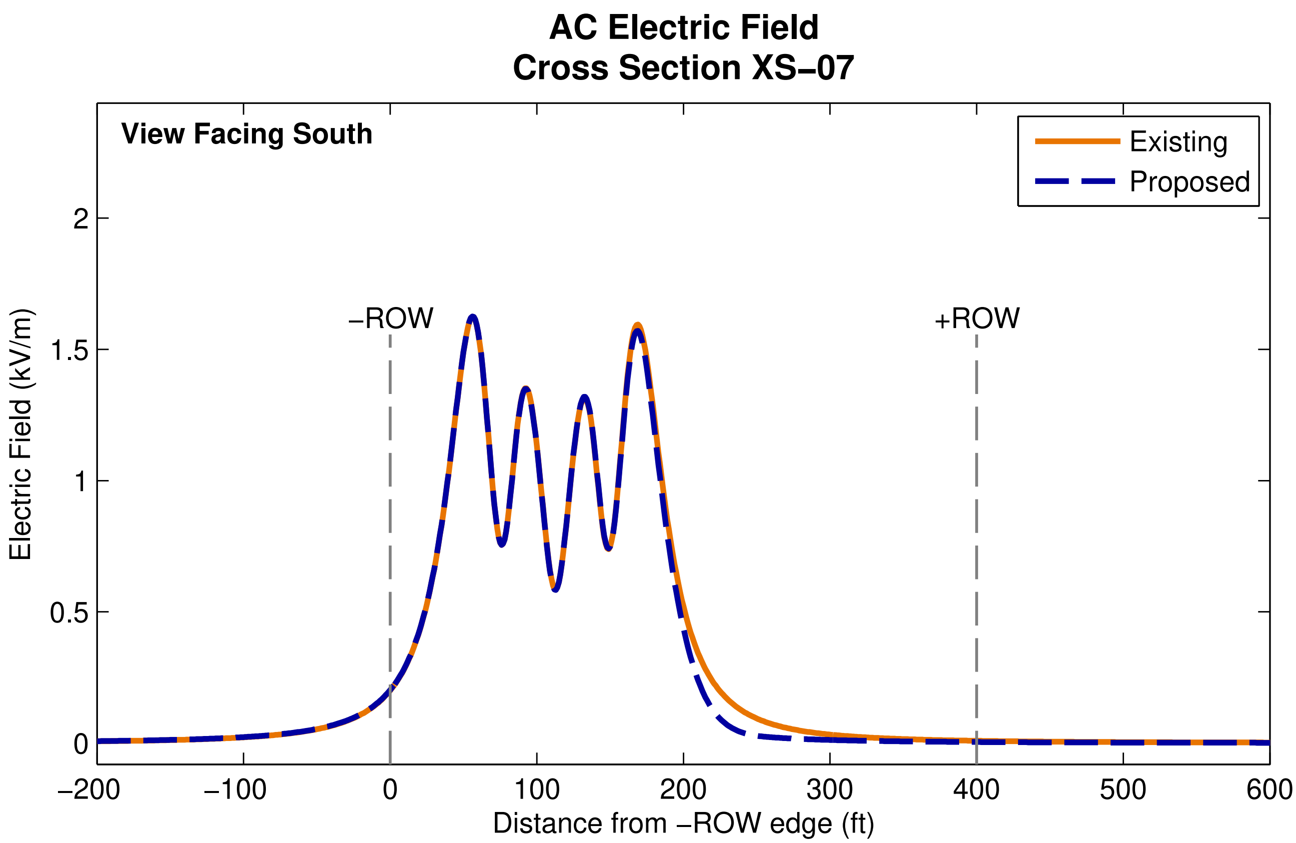

Figure C-33. Calculated AC electric-field profiles along XS-07.

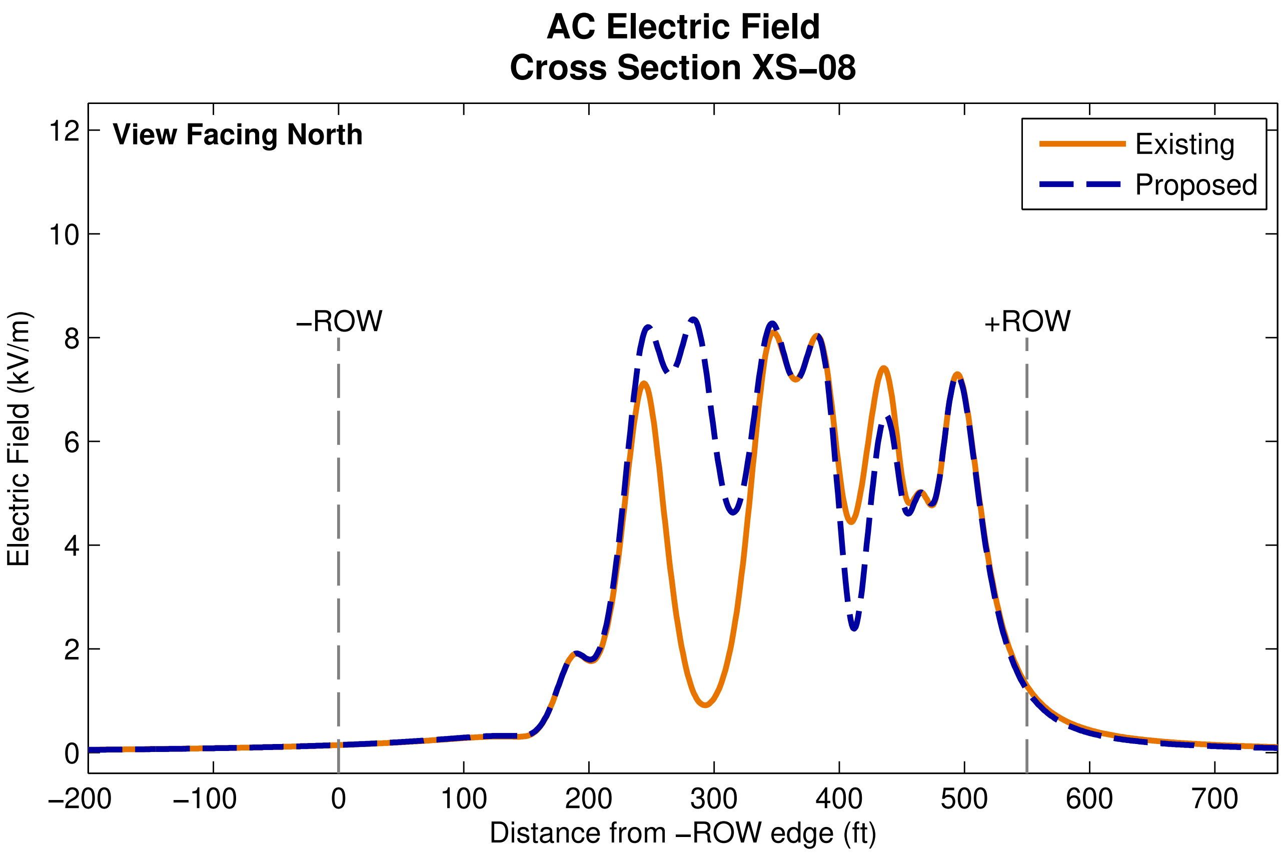

Figure C-34. Calculated AC electric-field profiles along XS-08.

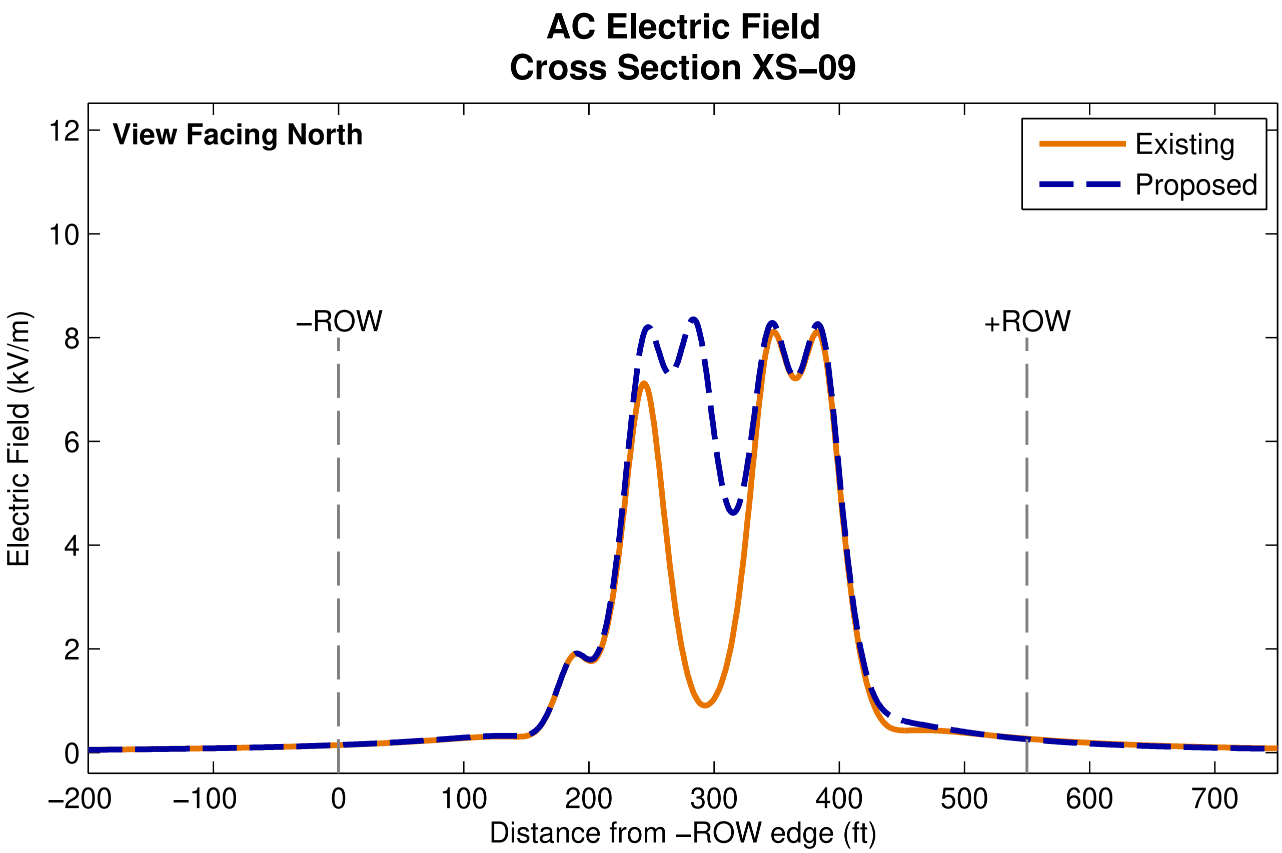

Figure C-35. Calculated AC electric-field profiles along XS-09.

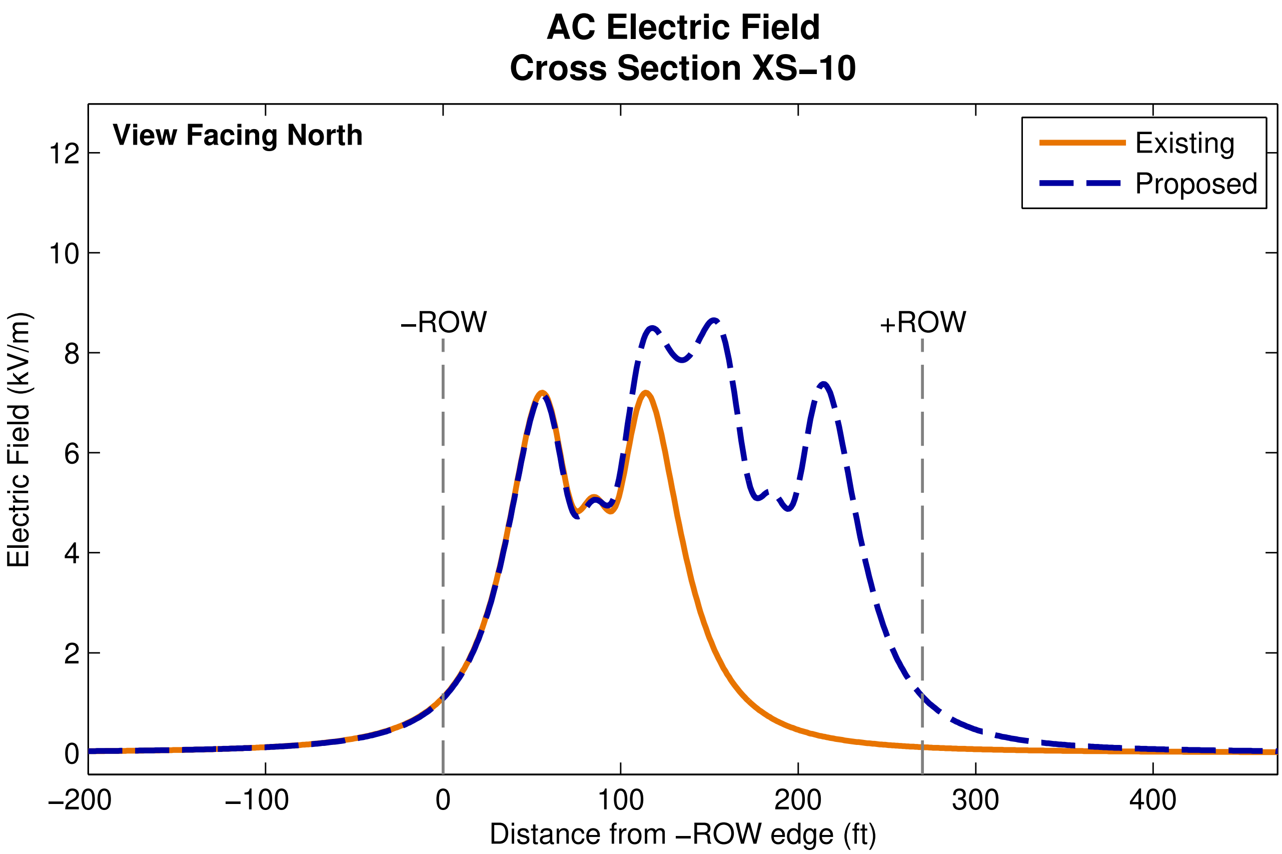

Figure C-36. Calculated AC electric-field profiles along XS-10.

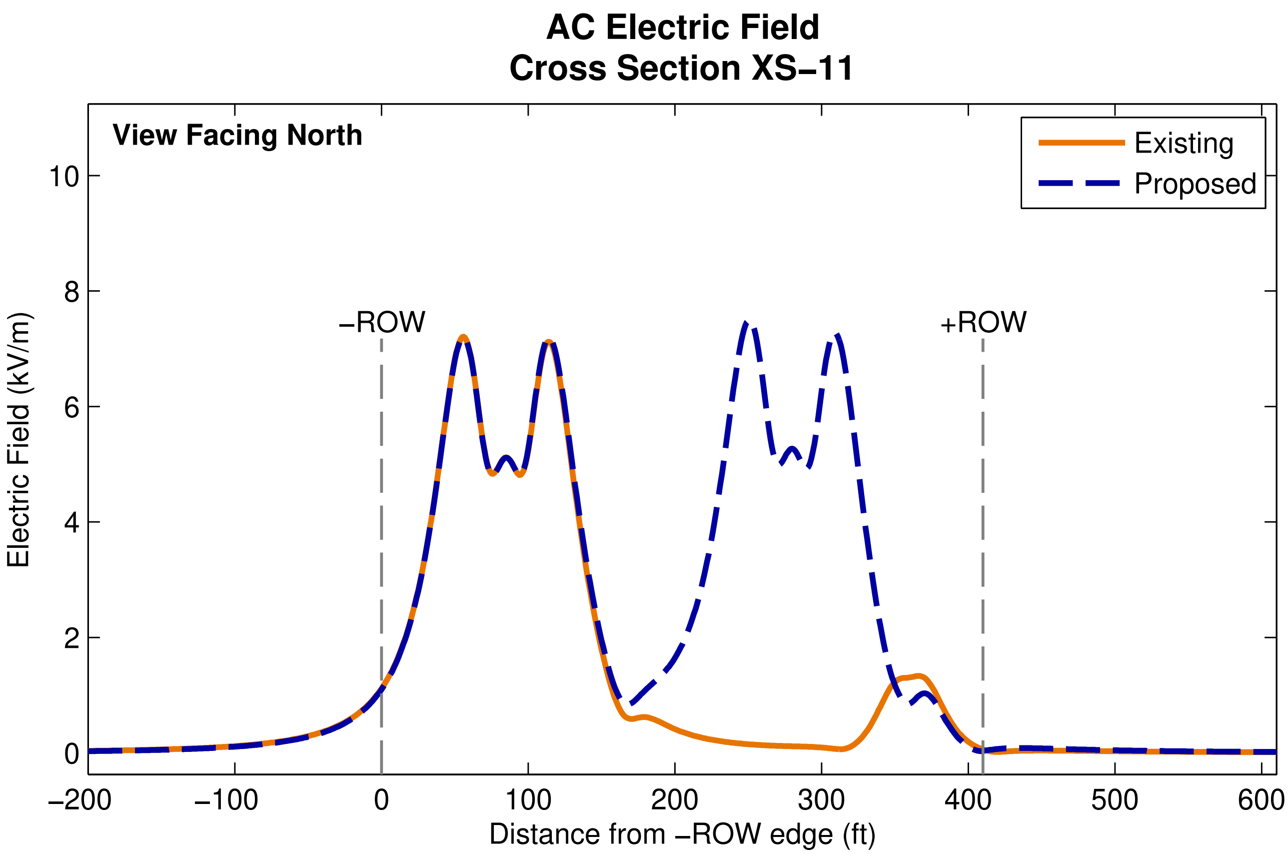

Figure C-37. Calculated AC electric-field profiles along XS-11.

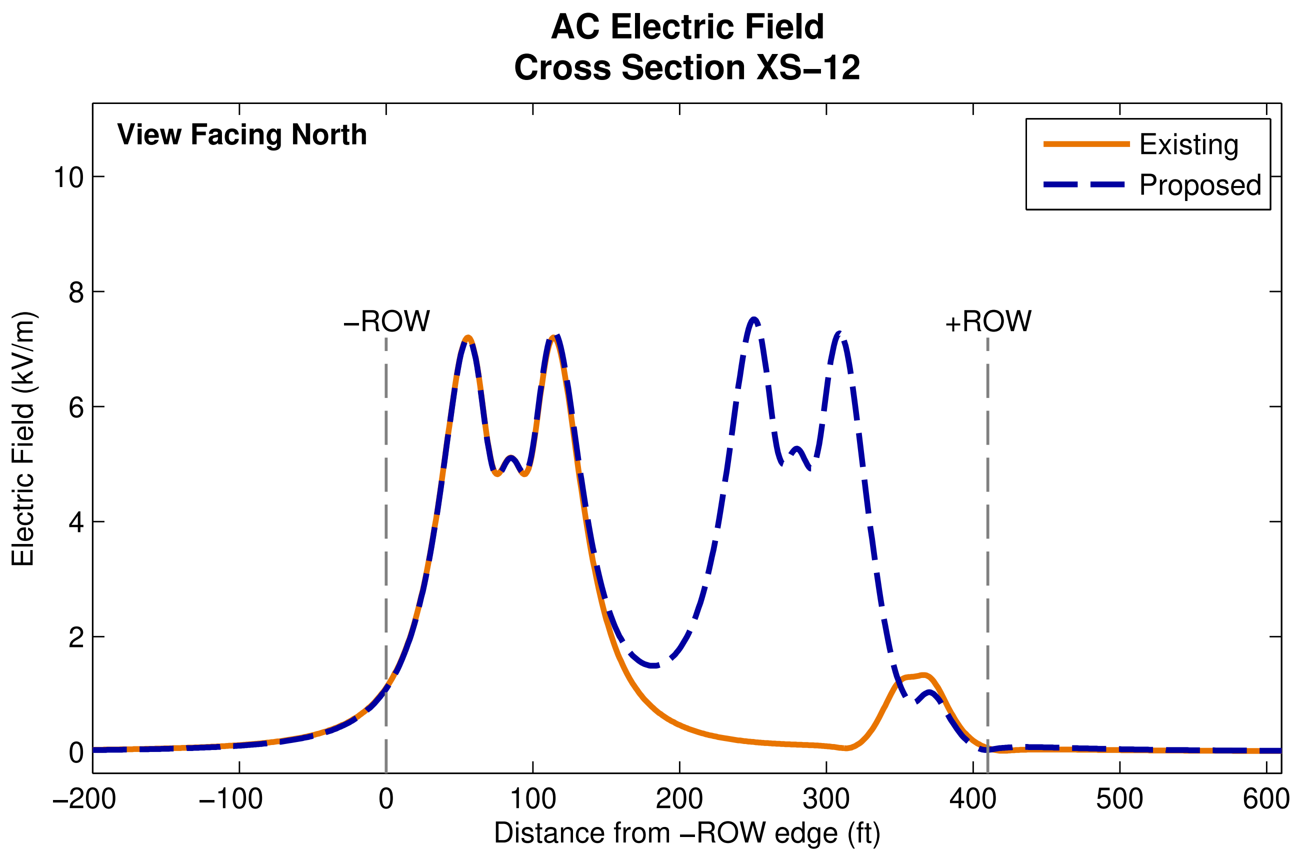

Figure C-38. Calculated AC electric-field profiles along XS-12.

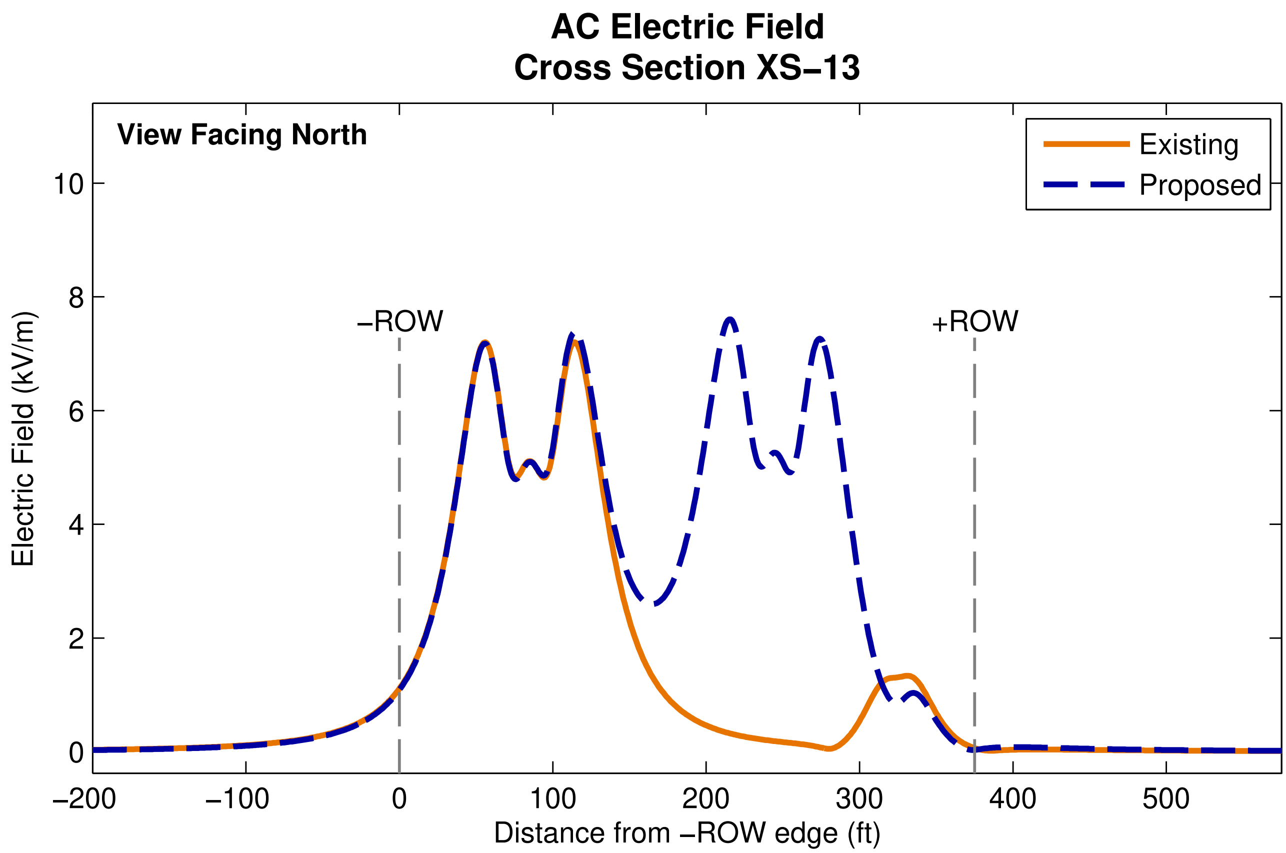

Figure C-39. Calculated AC electric-field profiles along XS-13.

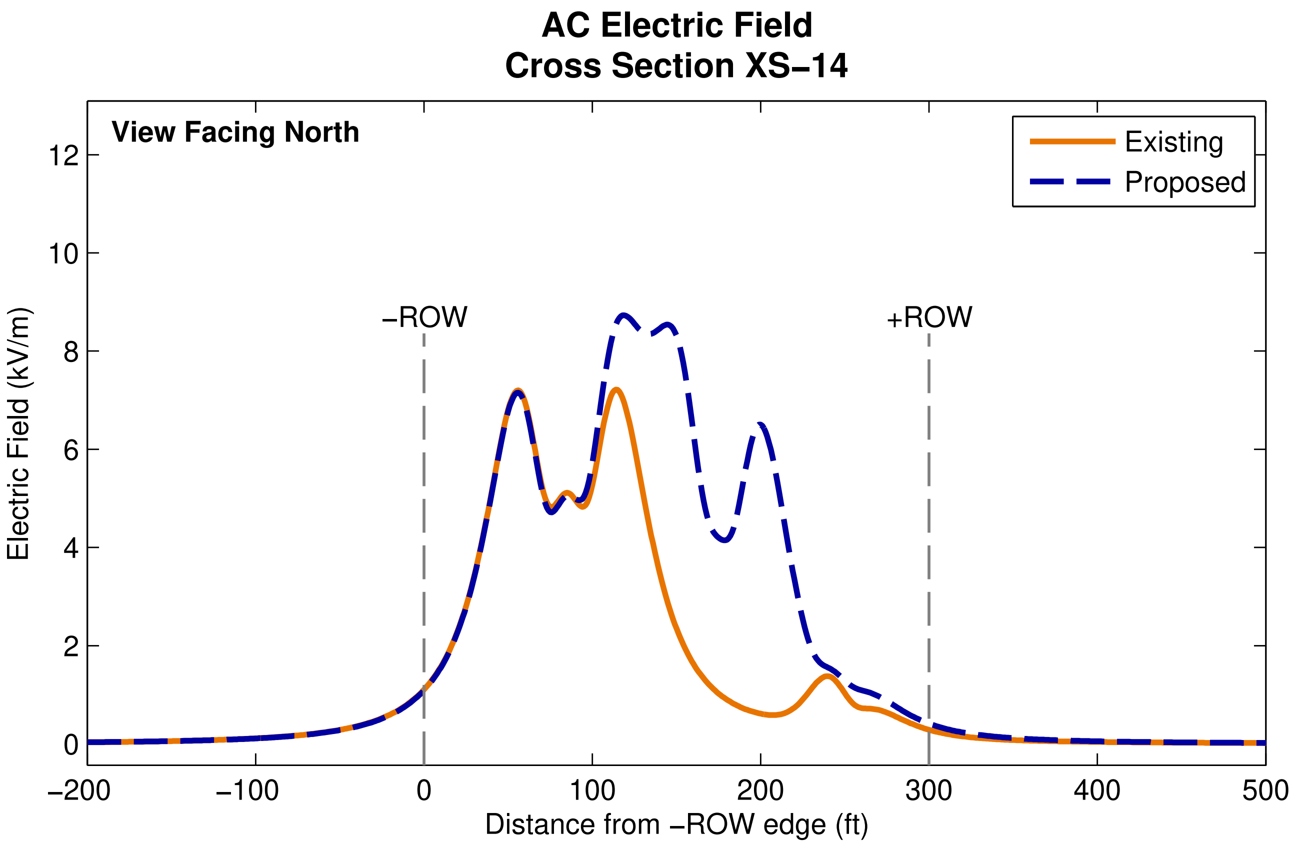

Figure C-40. Calculated AC electric-field profiles along XS-14.

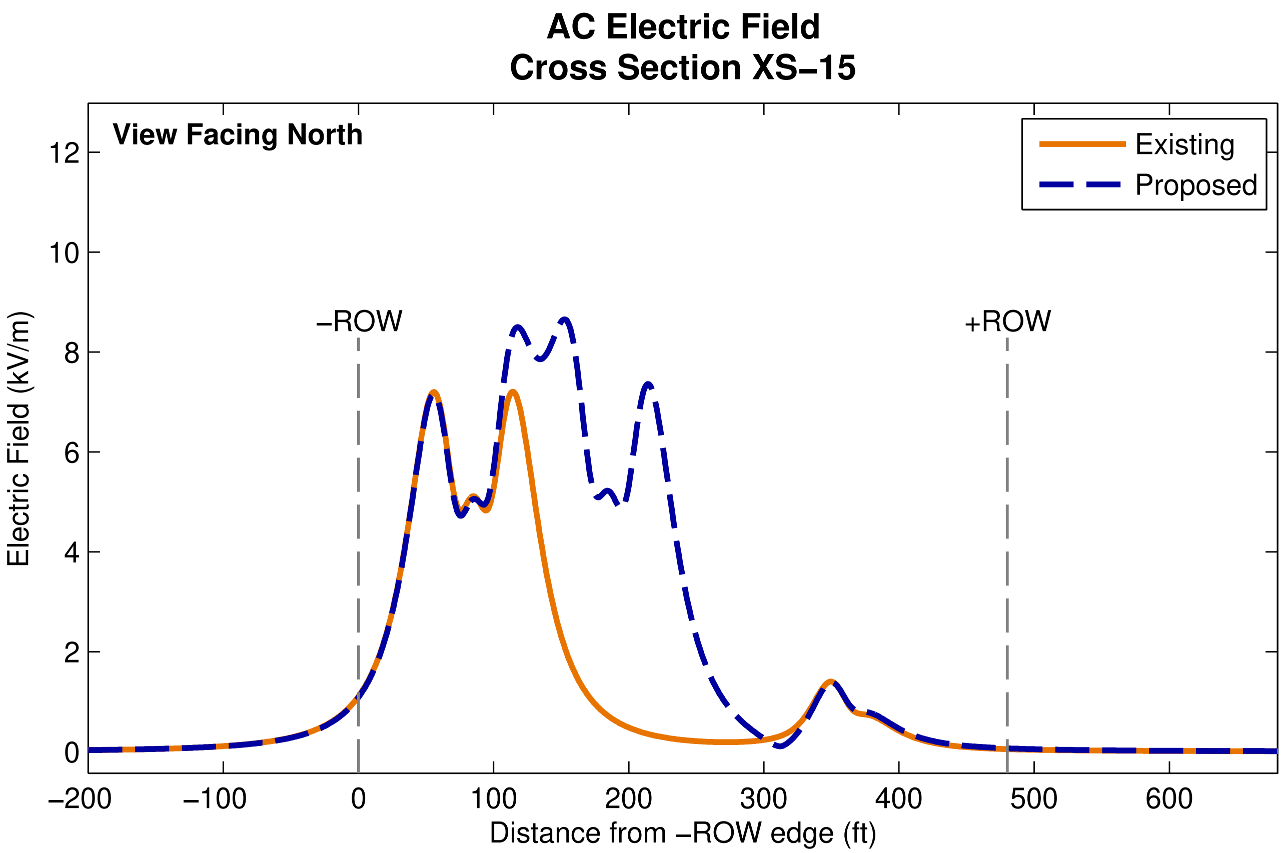

Figure C-41. Calculated AC electric-field profiles along XS-15.

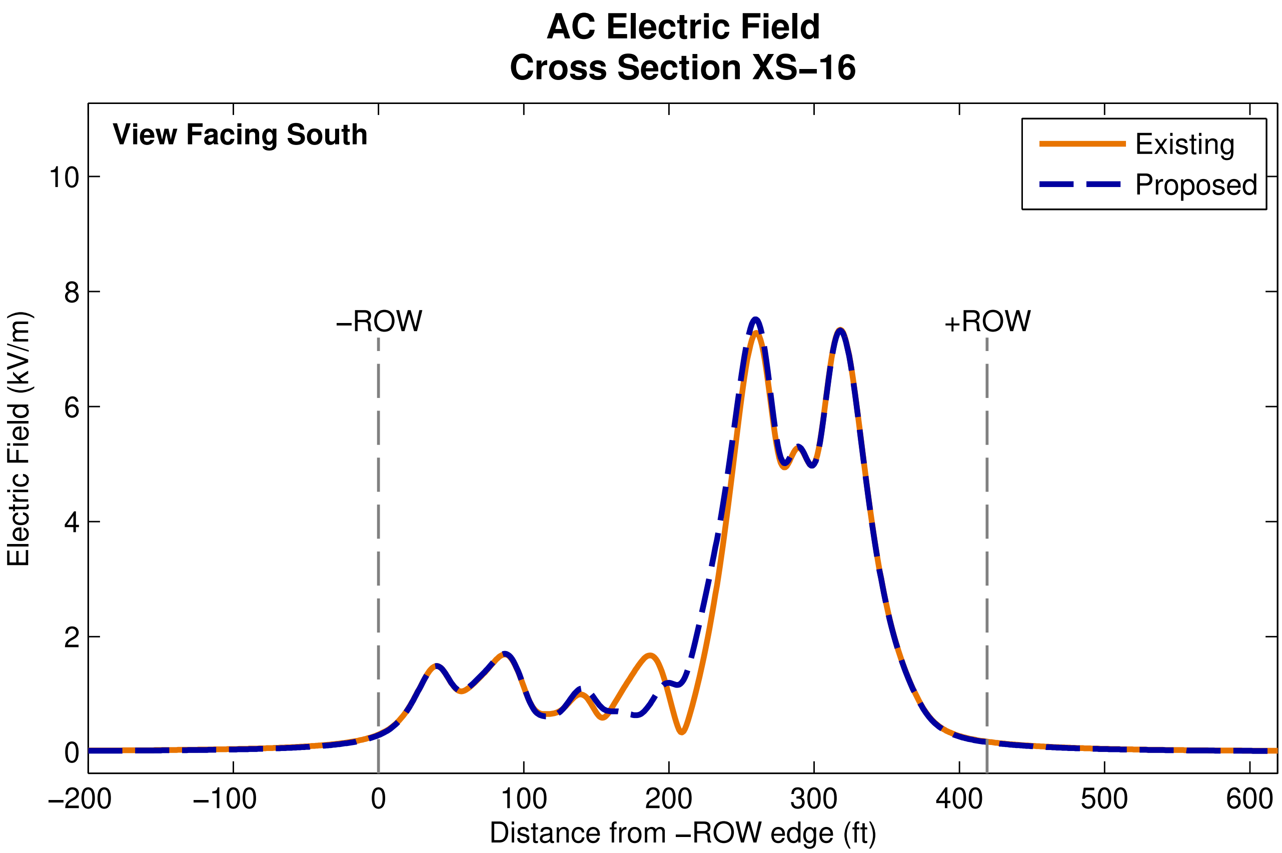

Figure C-42. Calculated AC electric-field profiles along XS-16.

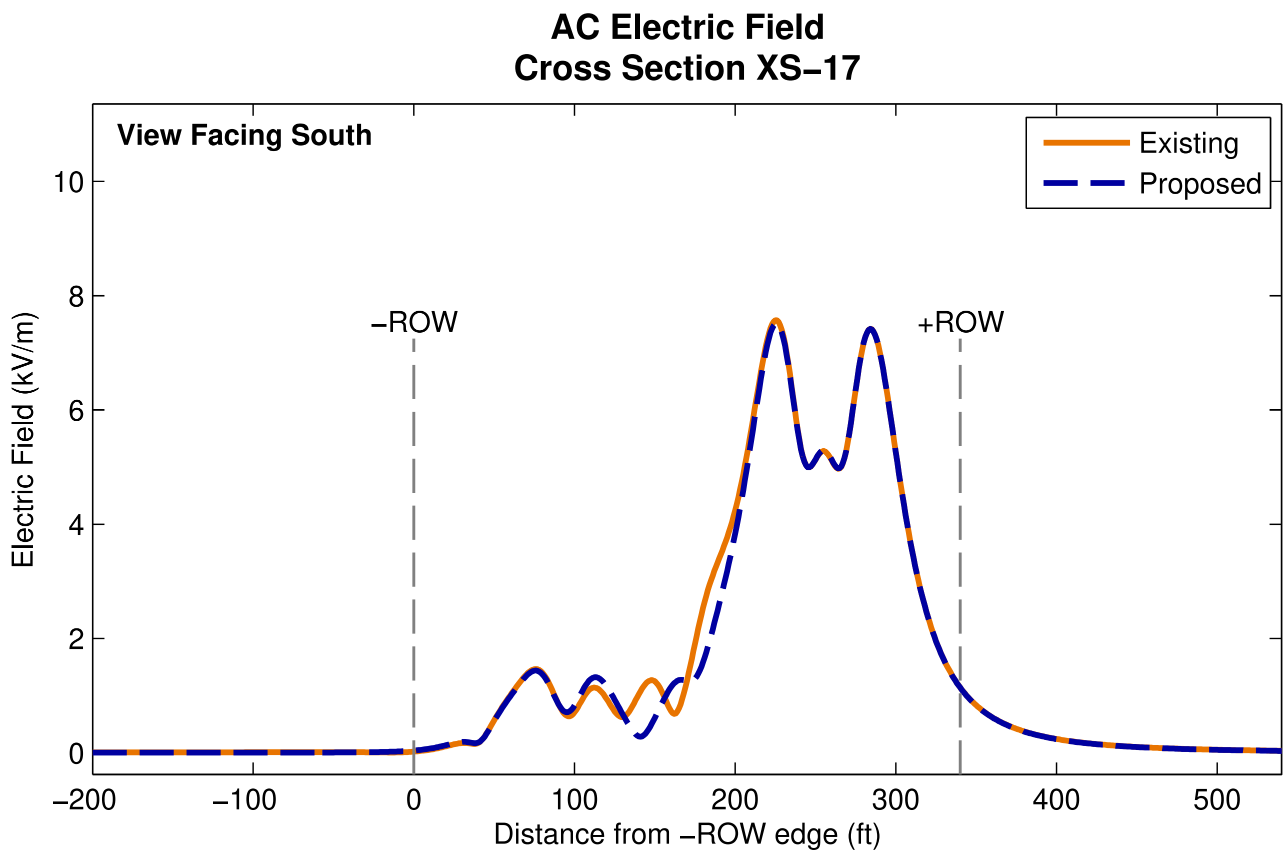

Figure C-43. Calculated AC electric-field profiles along XS-17.

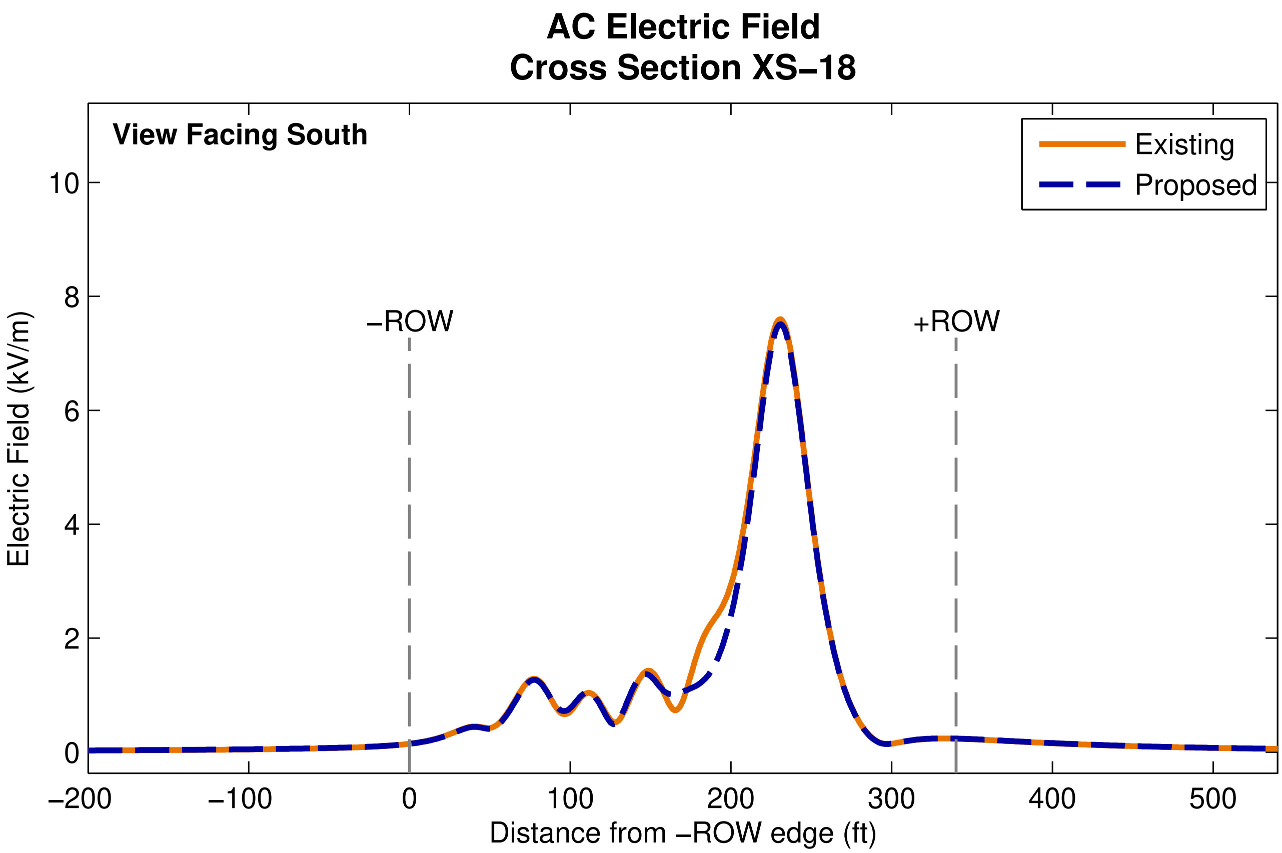

Figure C-44. Calculated AC electric-field profiles along XS-18.

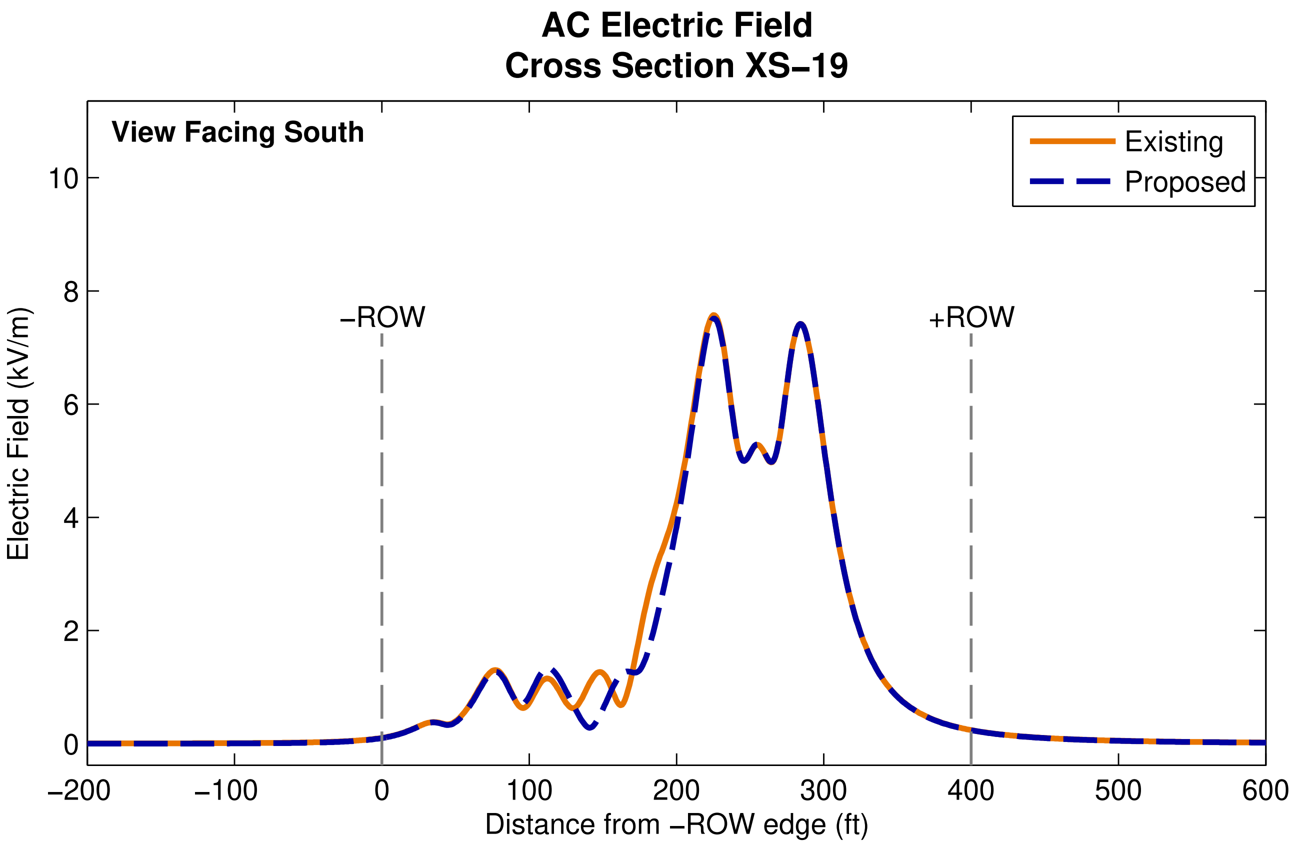

Figure C-45. Calculated AC electric-field profiles along XS-19.

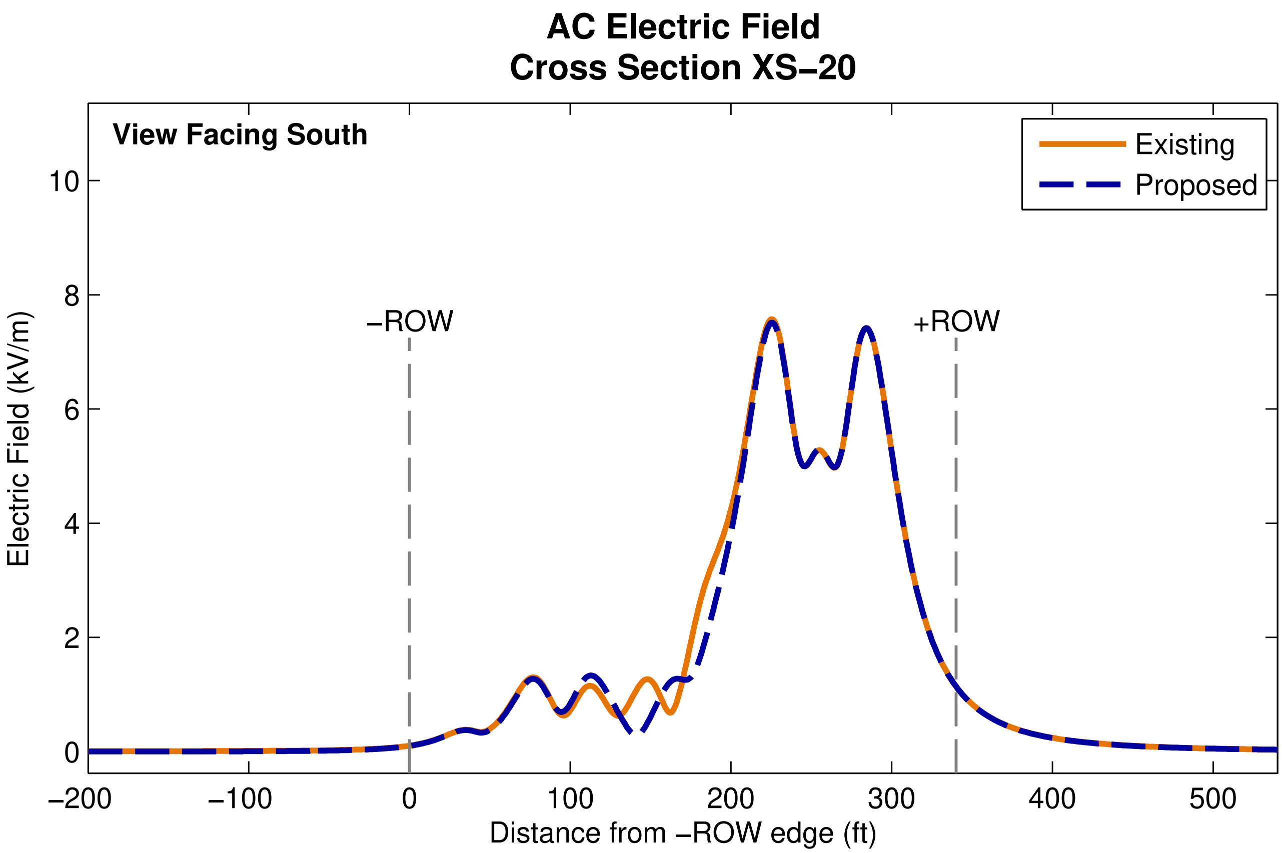

Figure C-46. Calculated AC electric-field profiles along XS-20.

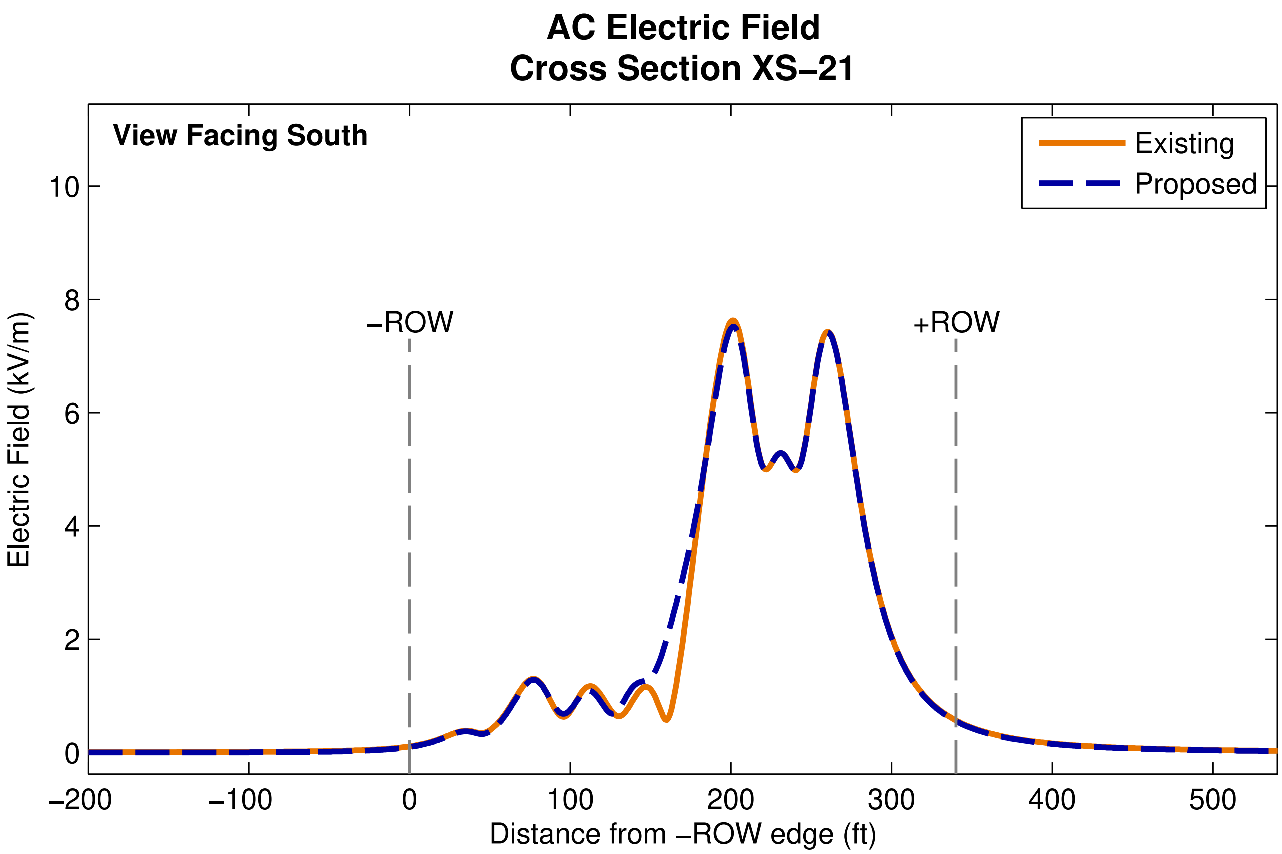

Figure C-47. Calculated AC electric-field profiles along XS-21.

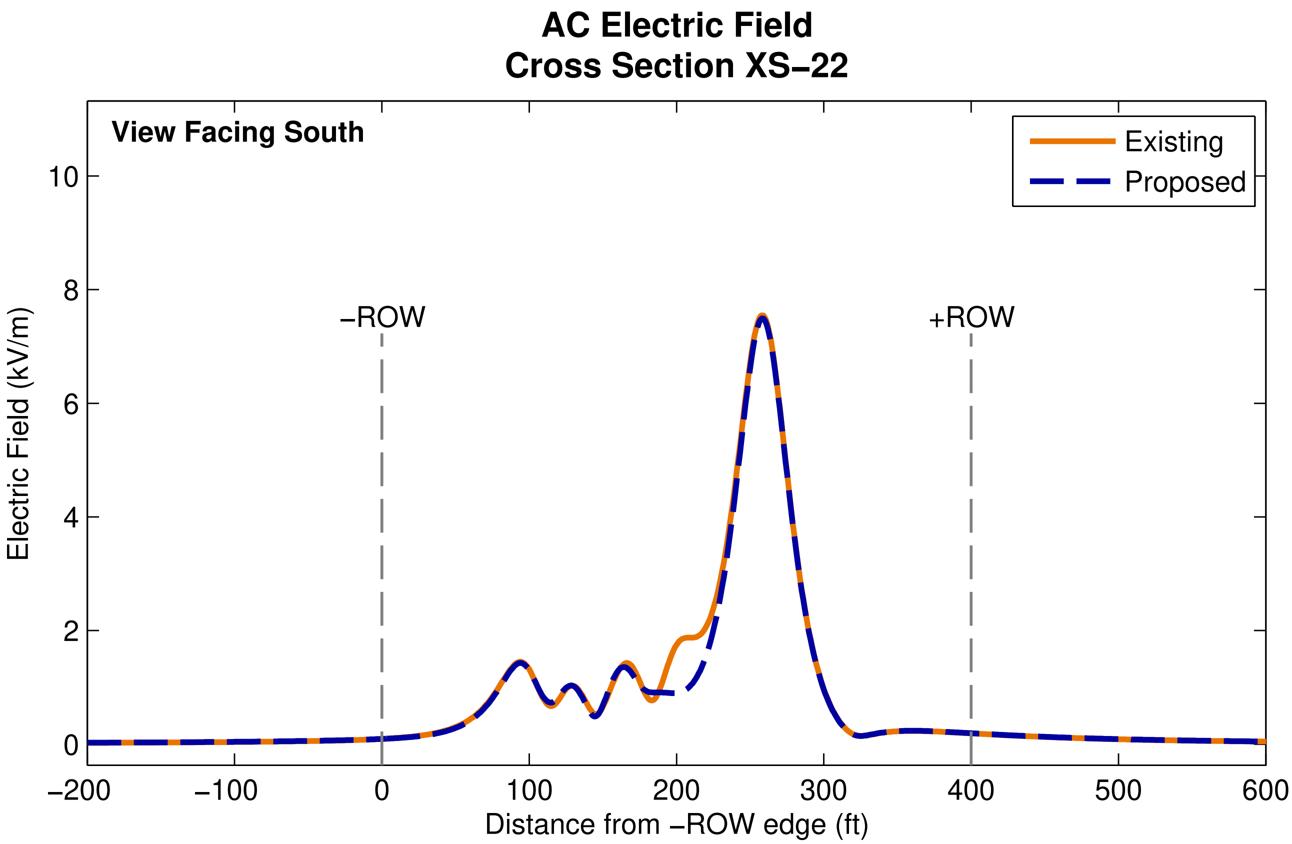

Figure C-48. Calculated AC electric-field profiles along XS-22.

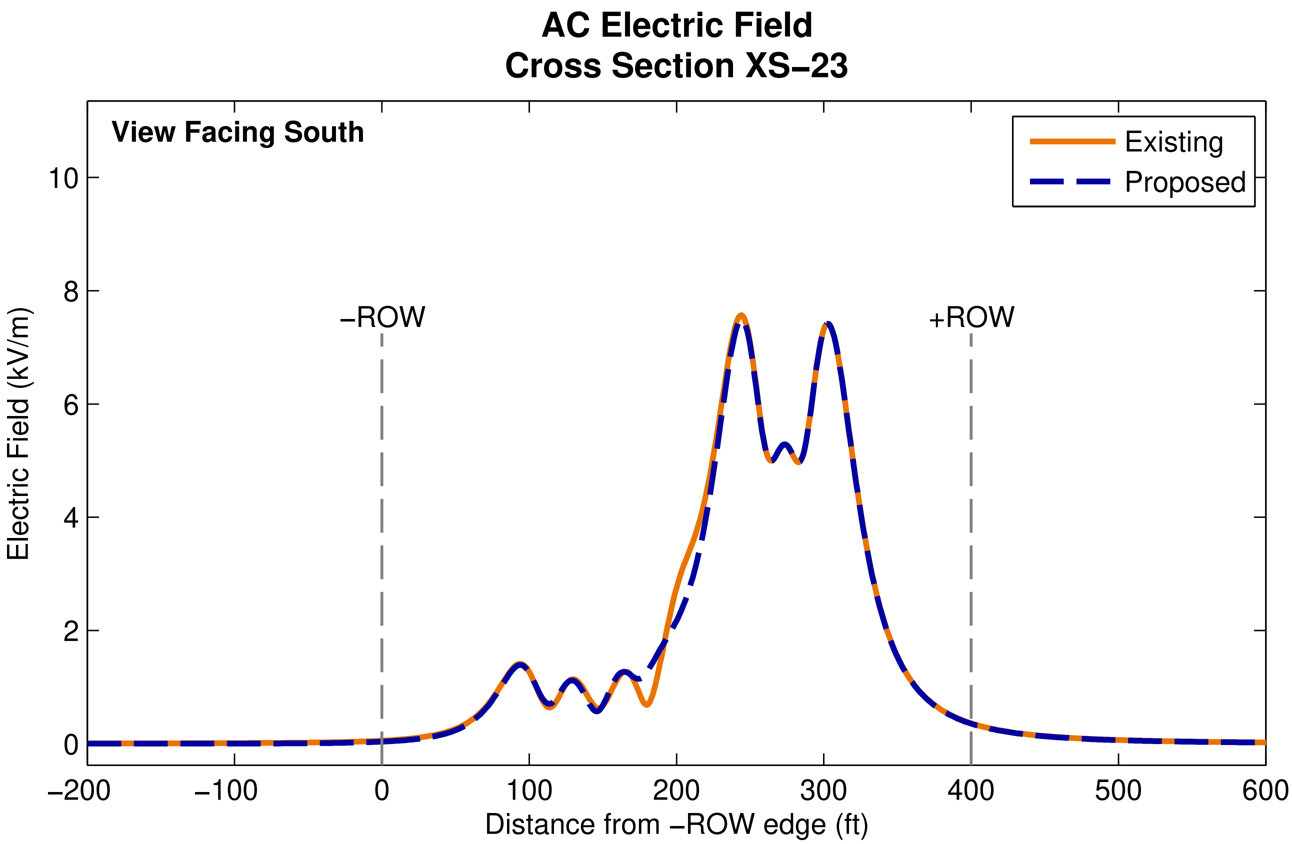

Figure C-49. Calculated AC electric-field profiles along XS-23.

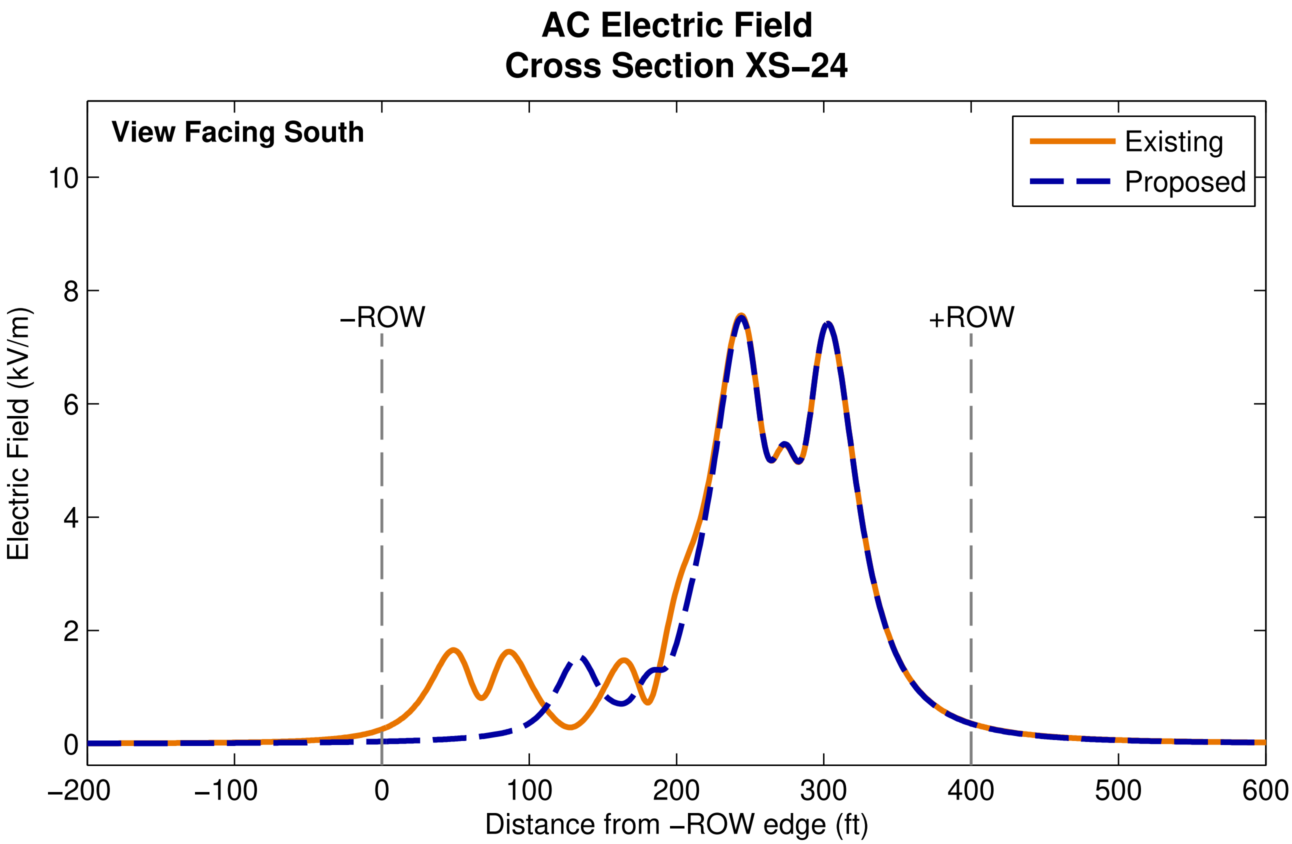

Figure C-50. Calculated AC electric-field profiles along XS-24.

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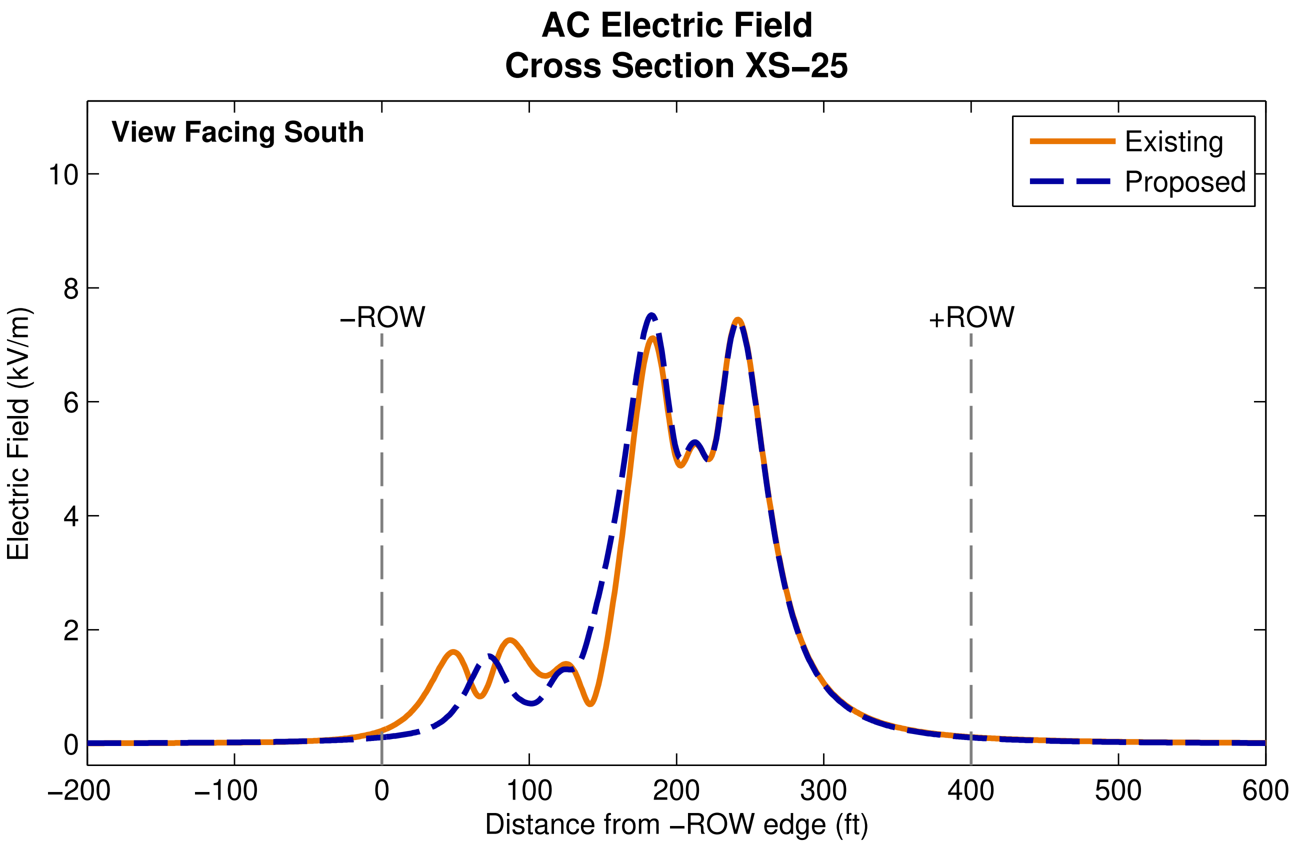

Figure C-51. Calculated AC electric-field profiles along XS-25.

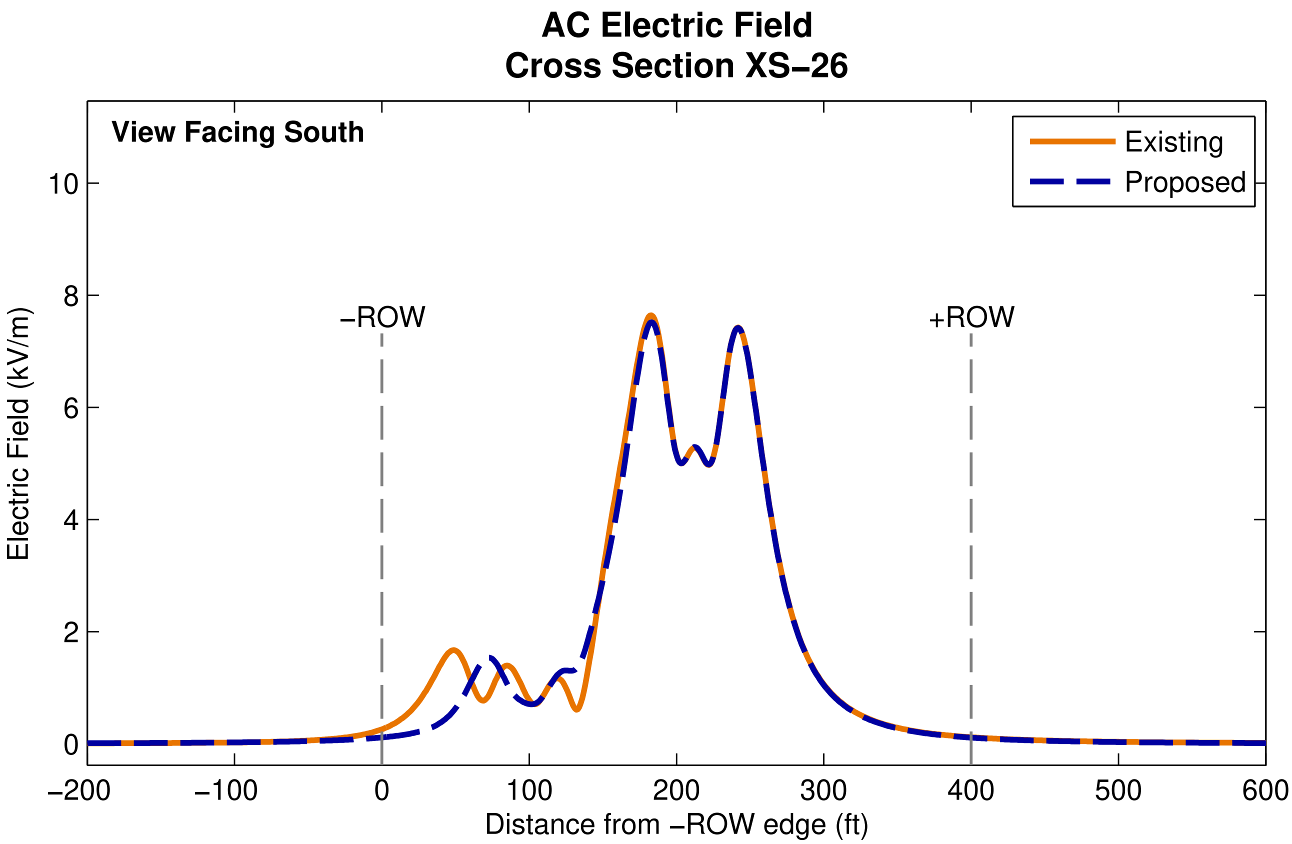

Figure C-52. Calculated AC electric-field profiles along XS-26.

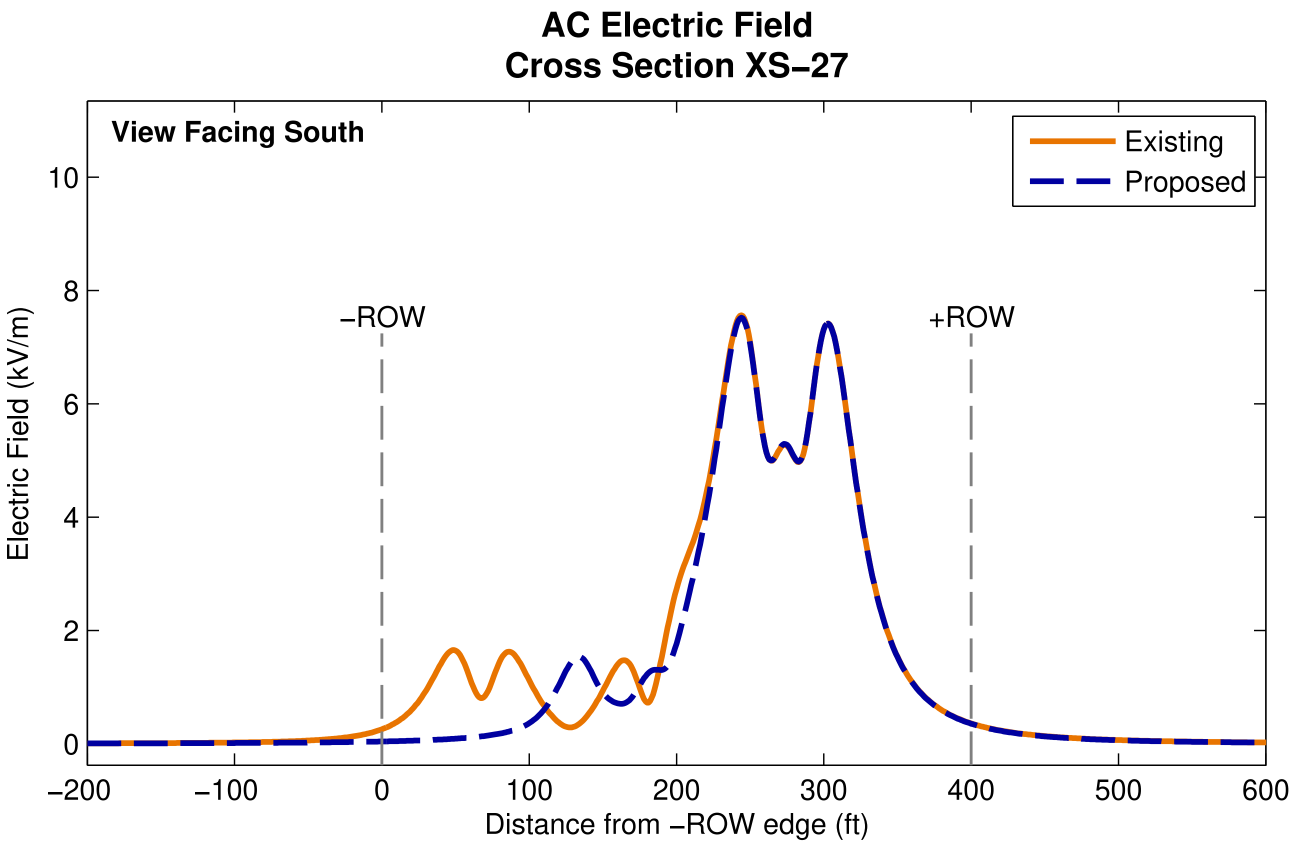

Figure C-53. Calculated AC electric-field profiles along XS-27.

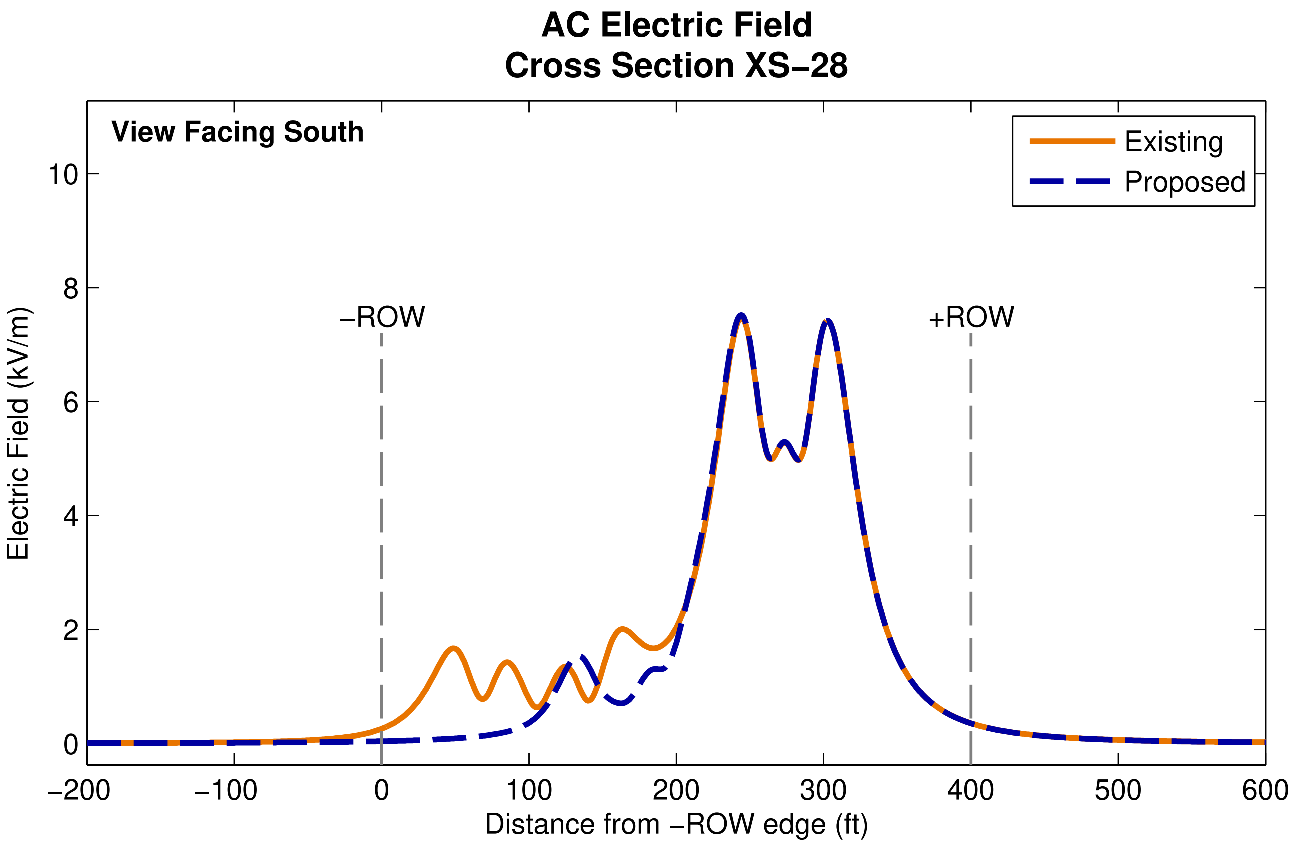

Figure C-54. Calculated AC electric-field profiles along XS-28.